# NAVAL SUPPORT ACTIVITY MID-SOUTH

# A-A SEQUENTIAL REMEDIATION TREATABILITY STUDY REPORT AOC A — NORTHSIDE FLUVIAL GROUNDWATER

**CTO-0094**

**Prepared for:**

**Department of the Navy**
**Southern Division**
**Naval Facilities Engineering Command**
**North Charleston, South Carolina**

**Prepared by:**

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**May 17, 2002**

ENSAFE

EnSafe Inc. ENVIRONMENTAL AND MANAGEMENT CONSULTANTS

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May 17, 2002

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Subject: CTO-0094; NSA Mid-South, AOC A, Millington, Tennessee

Document Transmittal - *A-A Sequential Remediation Treatability Study Report, AOC A - Northside Fluvial Groundwater, Revision 1,* May 17, 2002

Reference: Contract N62467-89-D-0318 (CLEAN II)

Dear Sir:

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Sincerely,

EnSafe Inc.

By: John Stedman, Jr.
Task Order Manager

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| a-a | anaerobic-aerobic |
| AOC | Area of Concern |
| BCT | BRAC Cleanup Team |
| bls | below land surface |
| BRAC | Base Closure and Realignment Act |
| BTEX | Benzene, Toluene, Ethylbenzene, Xylene |
| CFUs | colony forming units |
| CMS | Corrective Measures Study |
| $CO_2$ | carbon dioxide |
| CRP | Community Relations Plan |
| CSI | Confirmatory Sampling Investigation |
| DCA | dichloroethane |
| DCE | dichloroethene |
| DO | dissolved oxygen |
| DPT | direct push technology |
| E/A&H | EnSafe/Allen & Hoshall |
| EIC | Engineer-In-Charge |
| gpm | gallons per minute |
| HPC | heterotrophic plate count |
| HSWA | Hazardous and Solid Waste Amendments |
| ID | inside diameter |
| IDW | investigation-derived waste |
| IRP | Installation Restoration Program |
| $K_{xy}$ | hydraulic conductivity |
| kg | kilogram |
| lbs | pounds |
| MCLs | maximum contaminant levels |
| mg/L | milligram per liter |
| MNA | monitored natural attenuation |
| mV | millivolts |
| NSA | Naval Support Activity |

## ABBREVIATIONS AND ACRONYMS (continued)

| | |
|---|---|
| O&M | operations and maintenance |
| ORP | oxidation-reduction potential |
| PCE | tetrachloroethene |
| psi | pounds per square inch |
| PVC | polyvinyl chloride |
| QAPP | Quality Assurance Project Plan |
| RAB | Restoration Advisory Board |
| RBCs | risk-based concentrations |
| RCRA | Resource Conservation and Recovery Act |
| RFA/RFI | RCRA Facility Assessment/RCRA Facility Investigation |
| SAP | Sampling and Analysis Program |
| SWMU | solid waste management unit |
| TCE | trichloroethene |
| TDEC | Tennessee Department of Environment and Conservation |
| TKN | total kjeldahl nitrogen |
| TOC | total organic carbon |
| TS | treatability study |
| $\mu$g/kg | micrograms per kilogram |
| $\mu$g/L | micrograms per liter |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| VC | vinyl chloride |
| VOCs | volatile organic compounds |

# 1.0 INTRODUCTION

An anaerobic-aerobic (A-A) sequential remediation treatability study of volatile organic carbon (VOC) contamination in the fluvial deposits aquifer located on part of the former Northside of Naval Support (NSA) Mid-South, Millington, Tennessee was conducted by EnSafe Inc. from March to December 2000. This A-A treatability study is based on the *Corrective Measures Study (CMS) Work Plan* (EnSafe, 2000) for Area of Concern (AOC) A (the Northside fluvial groundwater), and methods presented in the *AOC A — Northside Fluvial Groundwater A-A Sequential Remediation Treatability Study Work Plan* (EnSafe, 1999).

The A-A sequential treatment technology is based on enhancing the biodegradation of VOCs that are present in the aquifer beneath AOC A, as described in Section 2 of this report. The primary purpose of the study was to determine the feasibility of using A-A sequencing to remediate the AOC A groundwater plume; specifically, the area of higher chlorinated solvent concentrations in the vicinity of monitoring well 007G04LF. A secondary purpose was to determine the chemical, biochemical, and physical impact of the treatability study on the aquifer.

Five wells were installed for the treatability study in February 2000 near existing wells 04LF and 04UF. Two additional monitoring wells were installed in August 2000. The wells installed for the treatability study include:

- One 4-inch inside diameter (ID) polyvinyl chloride (PVC) extraction well (57LF)
- Two 4-inch ID PVC reinjection wells (60LF, 61LF)
- Four 2-inch ID PVC monitoring wells (58LF, 59LF, 62LF, 63LF)

Each well was installed in the fluvial deposits, the top of which occurs at approximately 30 feet below land surface (bls) and extends to 75 feet bls in the treatability-study area. The extraction and reinjection wells each have 30-foot-long PVC screens for the system at the bottoms. The pumps, piping, instrumentation, tanks, electrical wiring, and housing were installed in February 2000, as described in the work plan (EnSafe, 1999). Section 5 of this report provides more information on well installation and the system setup.

The system operated from March 14, 2000 to December 15, 2000. During this time, periodic field monitoring data and monthly analytical data were collected, as described in Section 6 of this report. Results of the study are presented and analyzed in Section 7 of this document.

# 2.0 REMEDIAL TECHNOLOGY DESCRIPTION

## 2.1 Introduction

A-A sequential groundwater treatment, also known as "two-zone interception treatment," is designed for enhanced in-situ bioremediation of chlorinated solvent contamination in groundwater. The USEPA has demonstrated the treatment as an emerging technology under the Superfund Innovative Technology Evaluation (SITE) program.

## 2.2 Theory

Most chlorinated solvents at contaminated groundwater sites are amenable to biodegradation. However, compared with petroleum hydrocarbons, chlorinated solvents are more sensitive to groundwater oxidation-reduction potential (ORP), availability of natural organic carbon or anthropogenic organic substrates (e.g., benzene, toluene, ethyl benzene, and xylene [BTEX] or other man-made carbon sources), and natural groundwater electron acceptors such as dissolved oxygen, nitrate, sulfate, and carbon dioxide.

While petroleum hydrocarbons can serve as a primary organic substrate (food source that provides energy) or electron donor for microorganisms, chlorinated solvents — particularly the highly chlorinated solvents such as perchlorethylene (PCE) and trichloroethylene (TCE) — are not a direct food or energy source. PCE and TCE serve more as electron acceptors much as oxygen, nitrate, sulfate, and carbon dioxide do in BTEX or natural organic carbon degradation. In other words, anaerobic (absence of dissolved oxygen) or reduced conditions in an aquifer are more suitable to PCE and TCE degradation. Moreover, the more strongly reduced an aquifer is, the more readily PCE and TCE degrade.

The lesser chlorinated solvents such as 1,2-dichloroethylene (1,2-DCE) and vinyl chloride (VC) are more likely to serve as organic substrates (electron donors) or co-substrates and are more amenable to biodegradation in the presence of oxygen. These solvents are breakdown products (daughter compounds) of PCE and TCE degradation.

## 2.3 Treatment Process

The degree of anaerobicity or aerobicity of and aquifer can be estimated from redox measurements of the groundwater it contains. The lower the redox potential (measured in millivolts) of an aquifer, the more anaerobic or strongly reducing it is. In general, redox potentials less than +50 millivolts (mV) represent anaerobic (reducing) conditions. If redox measurements near a PCE and/or TCE plume are greater than +50 mV, nutrients (nitrate and phosphate compounds) and substrate (organic carbon) can be added to consume oxygen and drive the system to more strongly anaerobic or reducing conditions. Generally, enough carbon is added to create anaerobic conditions and be available as a food source while highly chlorinated solvents such as PCE and TCE are subsequently degraded. Conversely, if redox measurements near a 1,2-DCE and/or VC plume are less than +50 mV, air sparging of the aquifer can be used to increase oxygen availability and allow maximum biological consumption of substrates such as 1,2-DCE and VC.

## 2.4 Methodology

Creating an anaerobic zone upgradient of an aerobic zone within a PCE/TCE-contaminated groundwater plume establishes a sequential A-A zone that can degrade these compounds sequentially to innocuous gaseous end products. Moreover, flow through these zones can be accelerated by installing low-flow extraction wells downgradient of the aerobic zone and reinjecting the extracted groundwater, which has ben amended with carbon and other nutrients as described below, upgradient of the anaerobic zone.

**Anaerobic Zone**

An anaerobic zone in the contaminated part of the aquifer is created by pumping groundwater from downgradient extraction wells and adding carbon and other nutrients to it aboveground before reinjecting the groundwater into upgradient wells. The groundwater is first pumped to an aboveground chemical amendment system where carbon (fructose or acetate) and nutrients (ammonium phosphate) are added before the water is reinjected into the aquifer. The carbon and nutrients provide a ready food source that stimulates microbial respiration, which consumes all the available oxygen in the treated groundwater.

This recirculation process (extraction and reinjection) continues until an anaerobic zone is gradually created near the reinjection wells. Highly chlorinated solvents such as PCE and TCE are amenable to reductive dechlorination (biological removal of the chloride atoms) under anaerobic conditions. In other words, after the anaerobic zone is established, microorganisms will turn to sources other than oxygen, such as the higher chlorinated VOCs, for respiration.

**Aerobic Zone**

Anaerobic reductive dechlorination results in the formation of lesser-chlorinated daughter products, namely VC and 1,2-DCE. However, these compounds break down more readily in an aerobic environment. Therefore, if needed, an aerobic zone may be created near the downgradient extraction wells by injecting air into the aquifer via sparging wells connected to an aboveground blower. Sparging is generally performed intermittently, based on groundwater dissolved oxygen (DO) concentrations in area monitoring wells. Carbon and nutrients can also be added to the air sparging wells to enhance the aerobic degradation of 1,2-DCE and VC. Aerobic degradation of VC forms innocuous end products such as ethane, ethene, carbon dioxide, and water.

# 3.0 SITE DESCRIPTION

## 3.1 Introduction

Twelve solid waste management units (SWMUs) were identified on the NSA Mid-South Northside for Resource Conservation and Recovery Act (RCRA), Confirmatory Sampling Investigation (CSI) or RCRA Facility Investigation (RFI) characterization. During the November 1994 direct push technology (DPT) groundwater screening investigation for the SWMU 7 (N-126 plating shop drywell; now part of AOC A) RFI, chlorinated solvents (e.g., TCE and DCE) were detected in groundwater in the fluvial deposits aquifer. As the area of investigation expanded while the nature and extent of contamination were being defined, it became apparent that groundwater contamination in the airfield apron area was widespread and that SWMU 7 was not the primary source. The focus of the SWMU 7 groundwater investigation then shifted from the dry well to the entire airfield apron area, and ultimately to the entire NSA Mid-South Northside, as scattered pockets of contaminated groundwater in the fluvial deposits were identified. As a result, the Base Closure and Realignment Act (BRAC) Cleanup Team (BCT) decided to take a "holistic" approach to the Northside groundwater investigation and any subsequent CMS, creating AOC A, the Northside fluvial groundwater, to be evaluated as one unit rather than on a site-by-site basis.

Although the fluvial deposits groundwater beneath a large part of the Northside is included in AOC A, the CMS will focus on three main areas: (1) the plume areas where the highest VOC contaminant concentrations have been detected on the east side of Building N-126 near monitoring well 007G04LF, (2) the area once occupied by former Building N-6, and (3) the plume area north of the main runway which appears to extend offsite. The treatability study described in this report was conducted in the area east of Building N-126 where the highest chlorinated solvent concentrations have been identified in the groundwater in the fluvial deposits. A site map of the treatability study area is included as Figure 3-1.

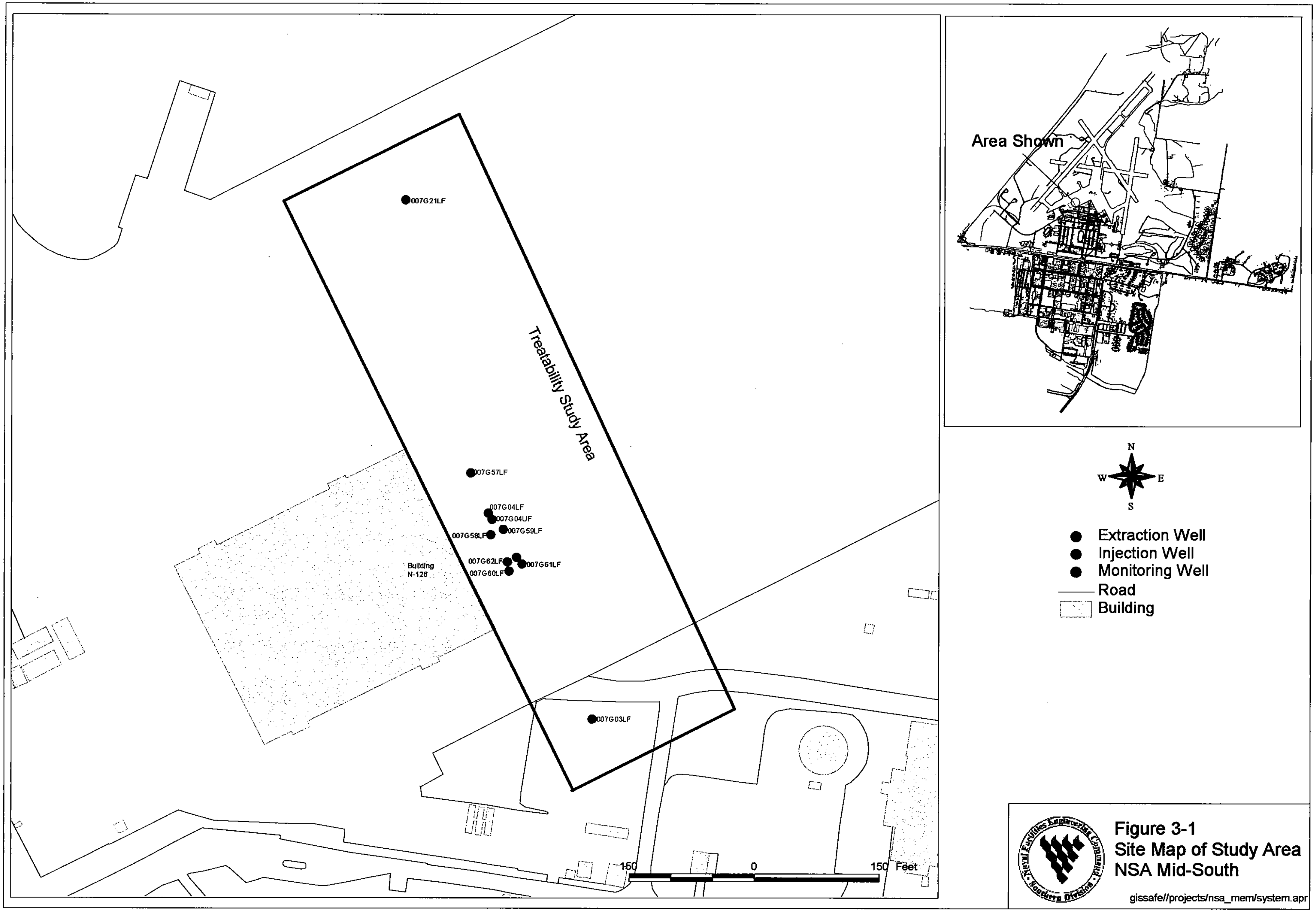


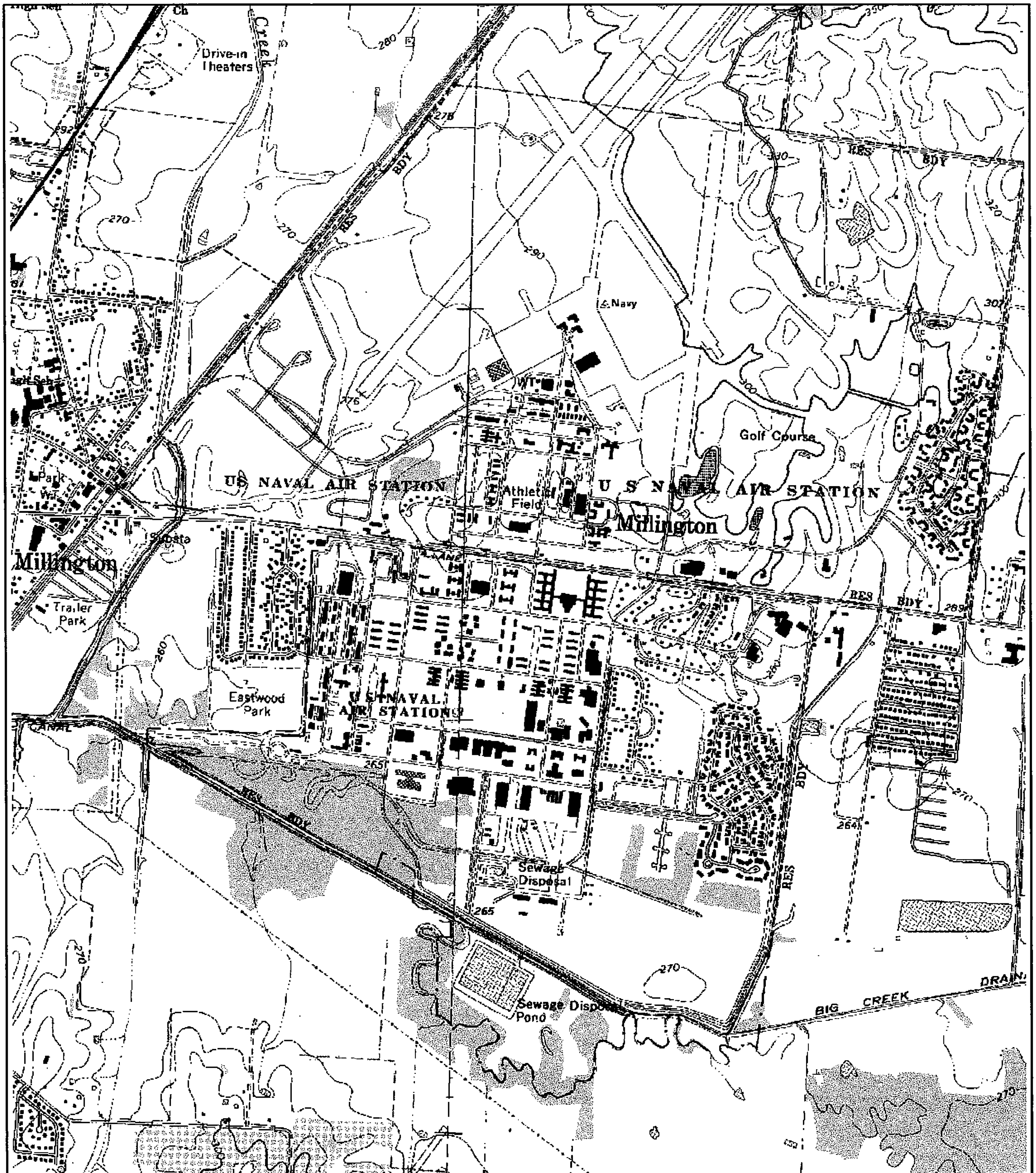

Figure 3-1
Site Map of Study Area
NSA Mid-South

## 3.2 Site Geology and Hydrogeology

The fluvial deposits beneath the former NSA Mid-South airfield apron area and throughout most of the Memphis area are made up of poorly sorted sand and gravel of Pleistocene to possibly Pliocene age, with minor amounts of clay as interstitial material, and occasional clay lenses generally no more than a few inches thick. Fine to medium sand in the upper sections coarsens with depth. Gravel occurs as lenses at various horizons in the fluvial deposits, but is more common in the lower part of the unit. The thickness of the fluvial deposits, which are fully saturated in the treatability study area, ranges from 26 to 64 feet within AOC A.

The fluvial deposits are overlain, and water in the formation is confined or semiconfined in by Pleistocene-age loess, a relatively low-permeability unit of silt and clayey silt that ranges from 25 to 45 feet thickness within AOC A. A perched groundwater zone occurs in the loess throughout much of NSA Mid-South and varies from 4 to 8 feet bls. However, this perched groundwater zone is absent beneath much of the apron where recharge is inhibited by the large area of concrete pavement.

The base of the fluvial deposits (ranges from about 70 to 100 feet bls) lies uncomformably on top of the Cockfield Formation of Eocene age, which, together with the underlying Cook Mountain formations (upper units of the Claiborne Group), forms the lower confining unit for the fluvial deposits and upper confining unit for th Memphis aquifer in the Memphis area. Water levels in monitoring wells screened in the Cockfield Formation, which is composed primarily of fine sand and silt with interbedded clay in the NSA Mid-0South area, are also confined by clay beds in the formation and are nearly equal to those in the fluvial deposits.




N
W E
S

USGS Bruswick , TN and
Millington, TN Quadrangles

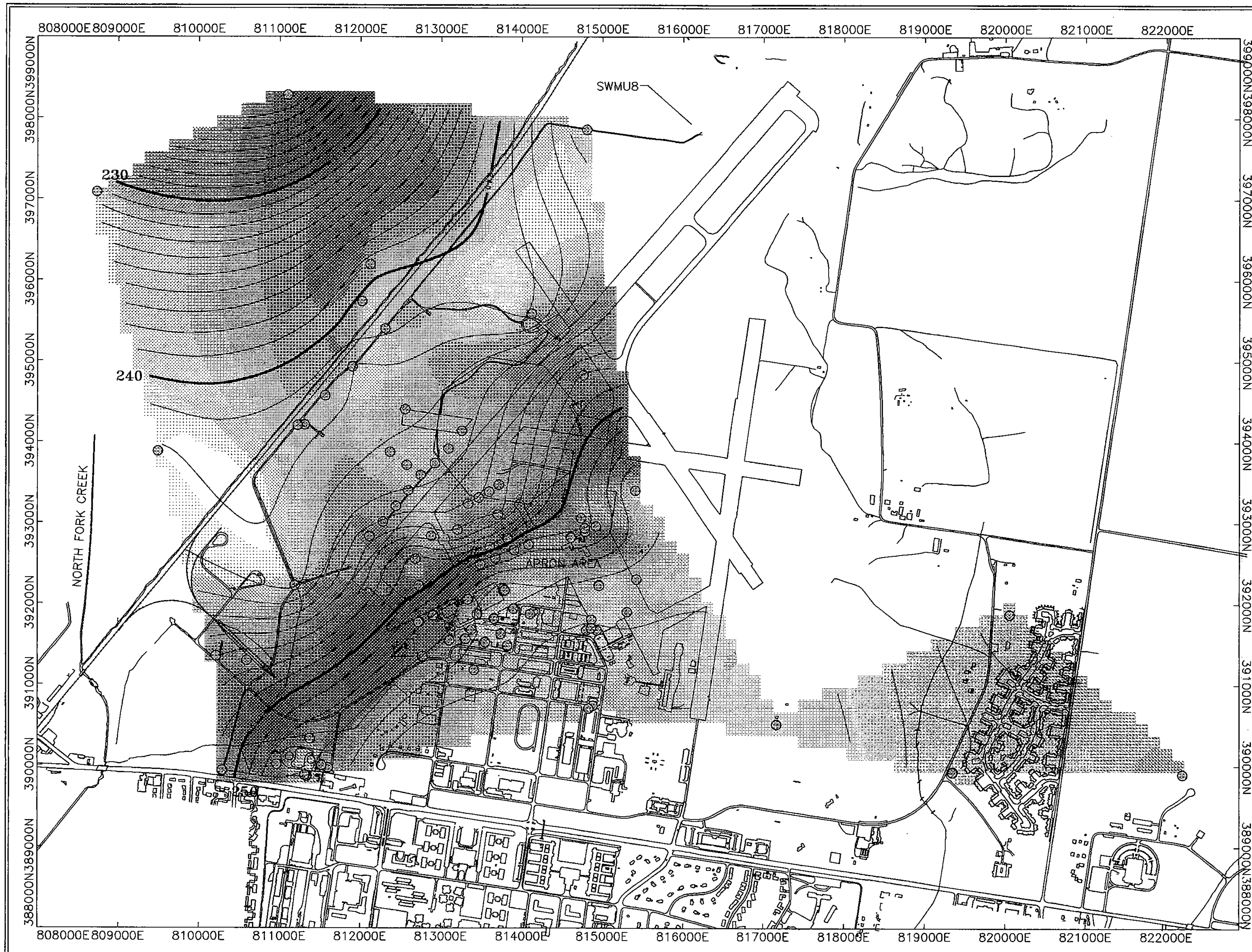
1000 0 1000 Feet

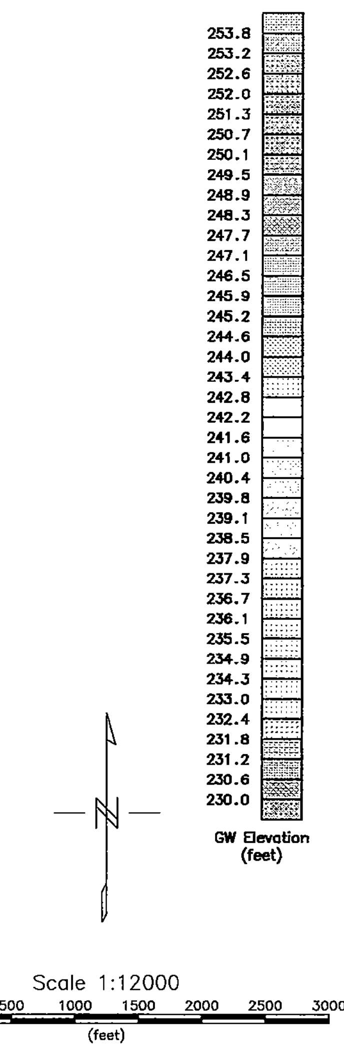
Figure 3-2
Site Topography
NSA Mid-South
Millington, Tennessee

GISSAFE//PROJECTS/NSA_MEM/VICINITY/VICINITY.APR

The Cook Mountain Formation, which contains the most aerially extensive clay in the upper part of the Claiborne Group in Memphis and Shelby County, serves as primary components of the confining unit separating groundwater in the fluvial deposits and Cockfield Formation from groundwater in the Memphis aquifer. The Cook Mountain Formation at NSA Mid-South consists predominantly of clay and silt; however, minor lenses of silty fine sand may be present locally. Geophysical logs from public supply wells indicate the Cook Mountain Formation ranges from 10 to 60 feet thick at NSA Mid-South (Carmichael et al., 1997). A topographic map of the NSA Mid-South Northside is shown on Figure 3-2.

In July 2000, EnSafe measured groundwater elevations in existing Northside monitoring wells screened in the fluvial deposits. Figure 3-3 shows groundwater in this unit flowing radially away from a south-to-northwest trending ridge. Potentiometric data from the apron area indicate that groundwater in the fluvial deposits is semiconfined to confined and flows north and west with an average hydraulic gradient of 0.004 to 0.008 foot per foot. Results of an aquifer test in the fluvial deposits southwest of the apron area produced an estimated horizontal hydraulic conductivity ($K_{xy}$) of 5.3 feet per day (Robinson et al., 1997), which yields a groundwater velocity from 31 to 62 feet per year, using a 25% assumed effective porosity value and the hydraulic gradients listed above. Likewise, another aquifer test in the fluvial deposits conducted north of the main runway produced an estimated $K_{xy}$ of 59 feet per day. Using this $K_{xy}$ value with the flatter gradients north of the runway (0.0017 feet per foot) and the same effective porosity, the groundwater velocity in this area is approximately 145 feet per year.




PLOT SUMMARY
- Groundwater elevation data collected 10 Jul 2000 (event 6)
- Dark gray dots show control data for this plot
- Drawing files: MEM-NOR1.DXF, MEM-NOR2.DXF
- Plot generated 02-20-01 via Geosoft

N:\WP51\USERS\LHUGHES\MEMPHIS\NORTH-GW\FEB2001\11.P01

Figure 3-3

JULY 2000 FLUVIAL DEPOSITS POTENTIOMETRIC MAP

A-A Sequential Study Treatability Report
AOC A - Northside Fluvial Groundwater
NSA Mid-South, Millington, TN

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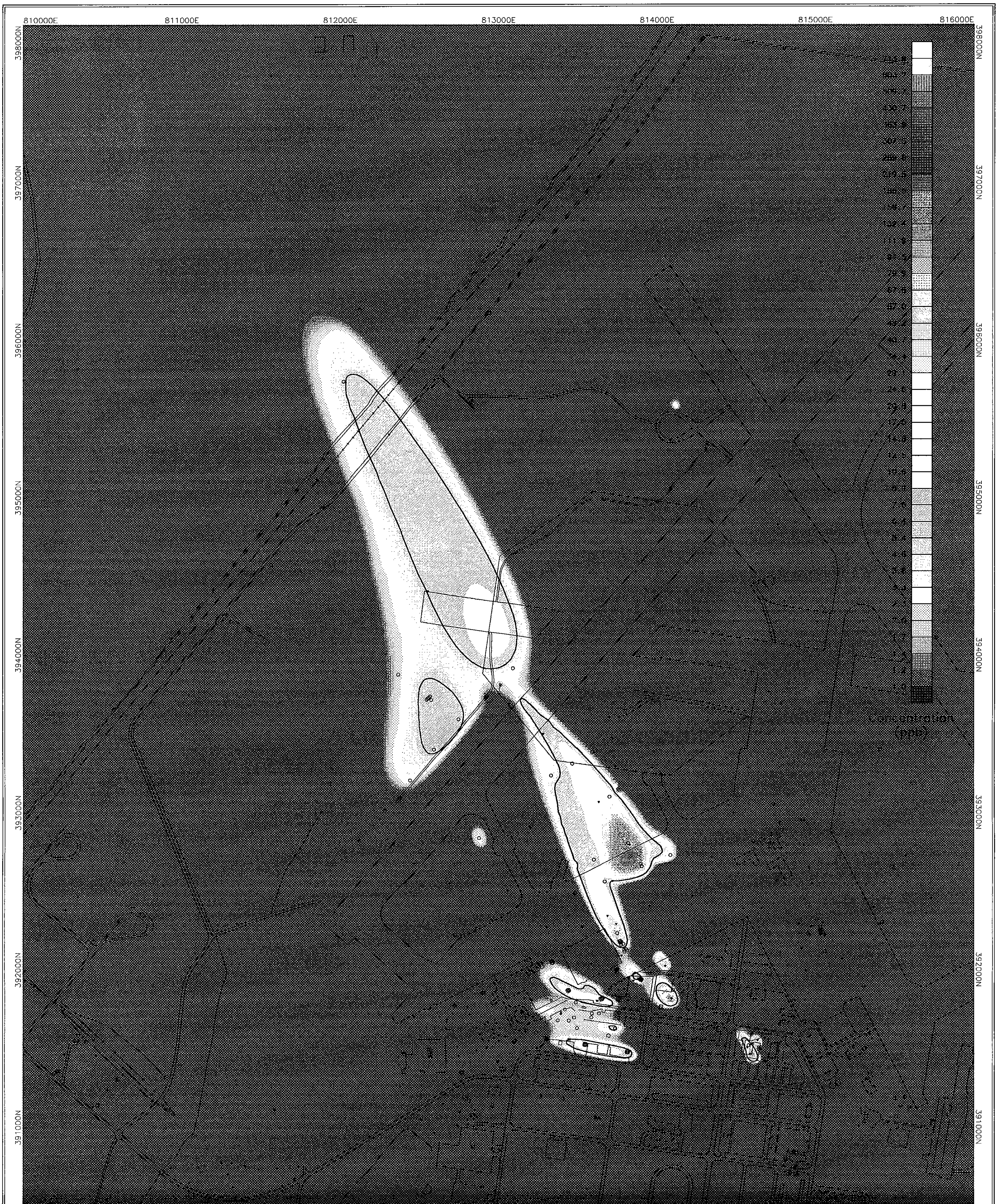
## 3.3 Nature and Extent of Contamination

A primary reason for designating the Northside fluvial deposits groundwater as an AOC was to expedite the CMS process through collectively evaluating all the SWMUs or contaminant source areas to the fluvial deposits groundwater in this area. The apron-area RFI showed that numerous areas containing multiple VOCs are present beneath the apron at concentrations exceeding maximum contaminant levels (MCLs), and thus warranting corrective measures. The RFI report and addendum for AOC A (EnSafe, 1998 and 2000) present all the fluvial deposits data collected in the apron area through July 1999. Data collected after July 1999 are presented in various technical EnSafe memorandum prepared for the BCT.

The fluvial-deposits data set is large and cumbersome because of multiple SWMUs, multiple sampling events with varying analytical suites, and the number of monitoring wells completed in three zones within the fluvial deposits (upper, middle, and lower parts). Primary contaminants of concern identified in the fluvial deposits are PCE, TCE, 1,2-DCE, 1,1-DCE, 1,2-dichloroethane (DCA) 1,1-DCA, carbon tetrachloride, chloroform, VC, and benzene. Because analytical summary tables for this data set are lengthy and are presented in the AOC A RFI report (EnSafe, 1998), they will not be included in this document. Since most of the significant contamination is from PCE, TCE, and their various daughter products, the treatability study monitored these solvents primarily. Figures 3-4 and 3-5 show the interpreted plumes for PCE and TCE, respectively, according to data collected during the RFI.




- monitoring well
- dpt

**red contour is MCL**

Scale 1:4000

250 0 250 500 750 (feet)

PLOT SUMMARY
- Contaminant conceptual model based on maximum PCE through 1999
- Red contour is MCL (5 ppb)

- Drawing files: NORTHWAT.DXF, NORTHBLD.DXF
- Plot generated 05-14-02 via Geosoft
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Figure 3-4

PCE PLUME MAP, MAXIMUM TO 1999
Fluvial Deposits Aquifer

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Treatability Study Report
NSA Mid-South
Millington, TN

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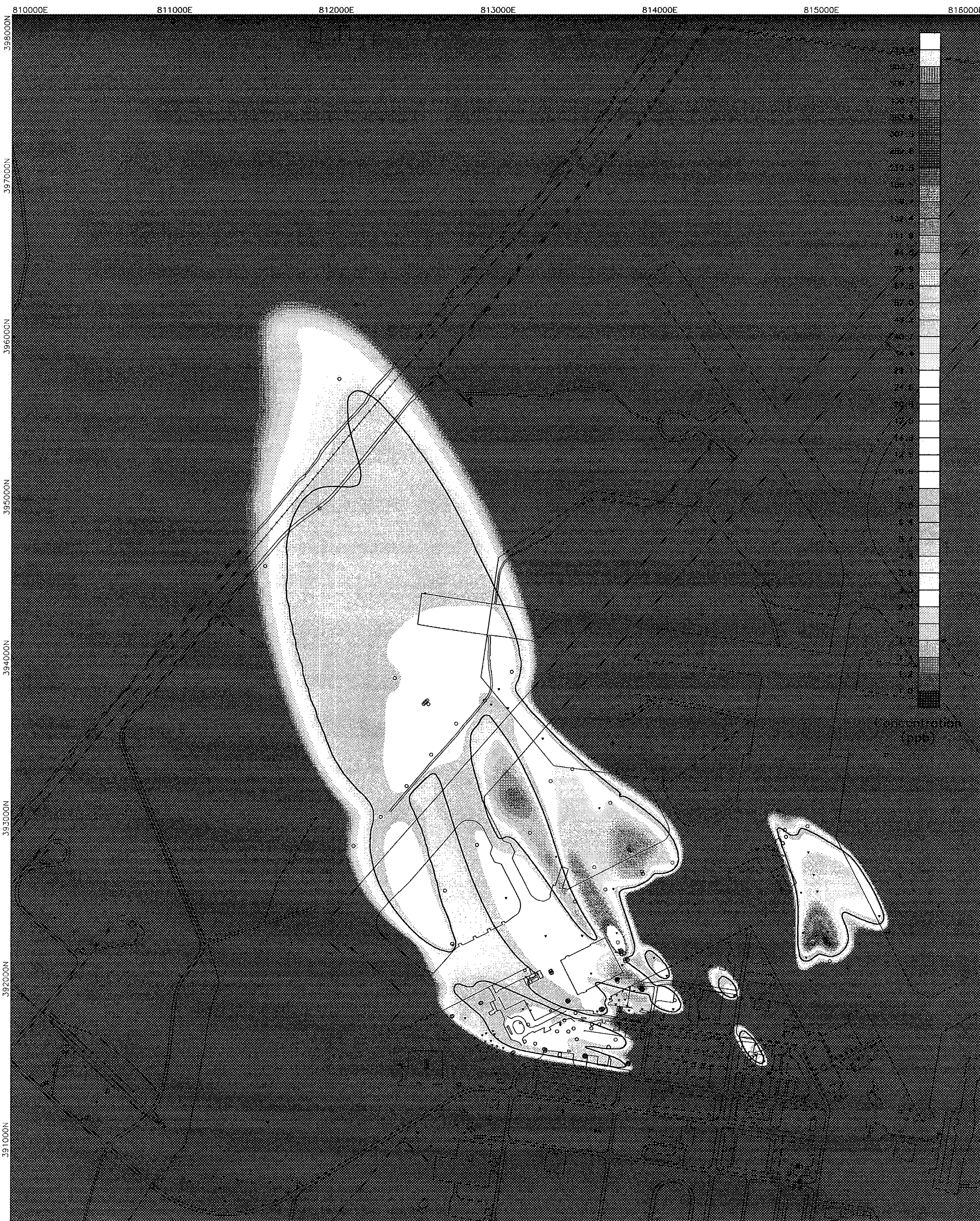


o **monitoring well**

. **dpt**

**red contour is MCL**

Scale 1:4000

250 0 250 500 750

(feet)

PLOT SUMMARY
- Contaminant conceptual model based on maximum TCE through 1999
- Red contour is MCL (5 ppb)

- Drawing files: NORTHWAT.DXF, NORTHBLD.DXF
- Plot generated 05-14-02 via Geosoft
- N:\WP51\USERS\LHUGHES\MEMPHIS\GEOCHEM\PLUMES\AA-TRT02\11.P01

Figure 3-5

TCE PLUME MAP, MAXIMUM TO 1999
Fluvial Deposits Aquifer

A-A Sequential Remediation
Treatability Study Report
NSA Mid-South
Millington, TN

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# 4.0 TREATABILITY STUDY OBJECTIVES

## 4.1 Primary Objectives

The main objective of this study was to determine the feasibility of using the A-A sequential technology to degrade and remediate the chlorinated VOC groundwater plumes in the fluvial deposits at AOC A. Although this technology is based on strong microbial principles, it has seen successful application only recently and is still considered an innovative technology. Furthermore, its feasibility often depends on site-specific chemical, geological, and hydrogeological variabilities that are difficult to reproduce in a laboratory. Therefore, a pilot-scale treatability study was needed to assess its effectiveness at AOC A.

The treatability study focused on the plume in the area of monitoring well 007G04LF. Study results will be used to compare this technology with other treatment alternatives and to provide cost and design data for full-scale implementation if this technology is selected as a final remedy or part of the final remedy for this site.

## 4.2 Secondary Objectives

Secondary objectives of the treatability study included evaluating field parameters necessary to monitor system operation such as DO, pH, oxidation-reduction potential (ORP), heterotrophic plate counts, nutrients, and total organic carbon (TOC). Changes in the values of these parameters (particularly DO) and the time period in which these changes occur can be used to determine how effectively groundwater is being amended to degrade chlorinated solvents. Another secondary objective was to monitor groundwater extraction and reinjection rates and changes in groundwater levels in the area monitoring wells to help evaluate groundwater recirculation patterns in the test area.

# 5.0 TREATABILITY SYSTEM SET-UP

## 5.1 System Elements

The A-A sequential system included the extraction well, reinjection wells, monitoring wells, and an aboveground groundwater chemical amendment system. The equipment layout is shown on Figure 5-1, while the system process and instrumentation diagram is shown on Figure 5-2.

### Groundwater Extraction Well

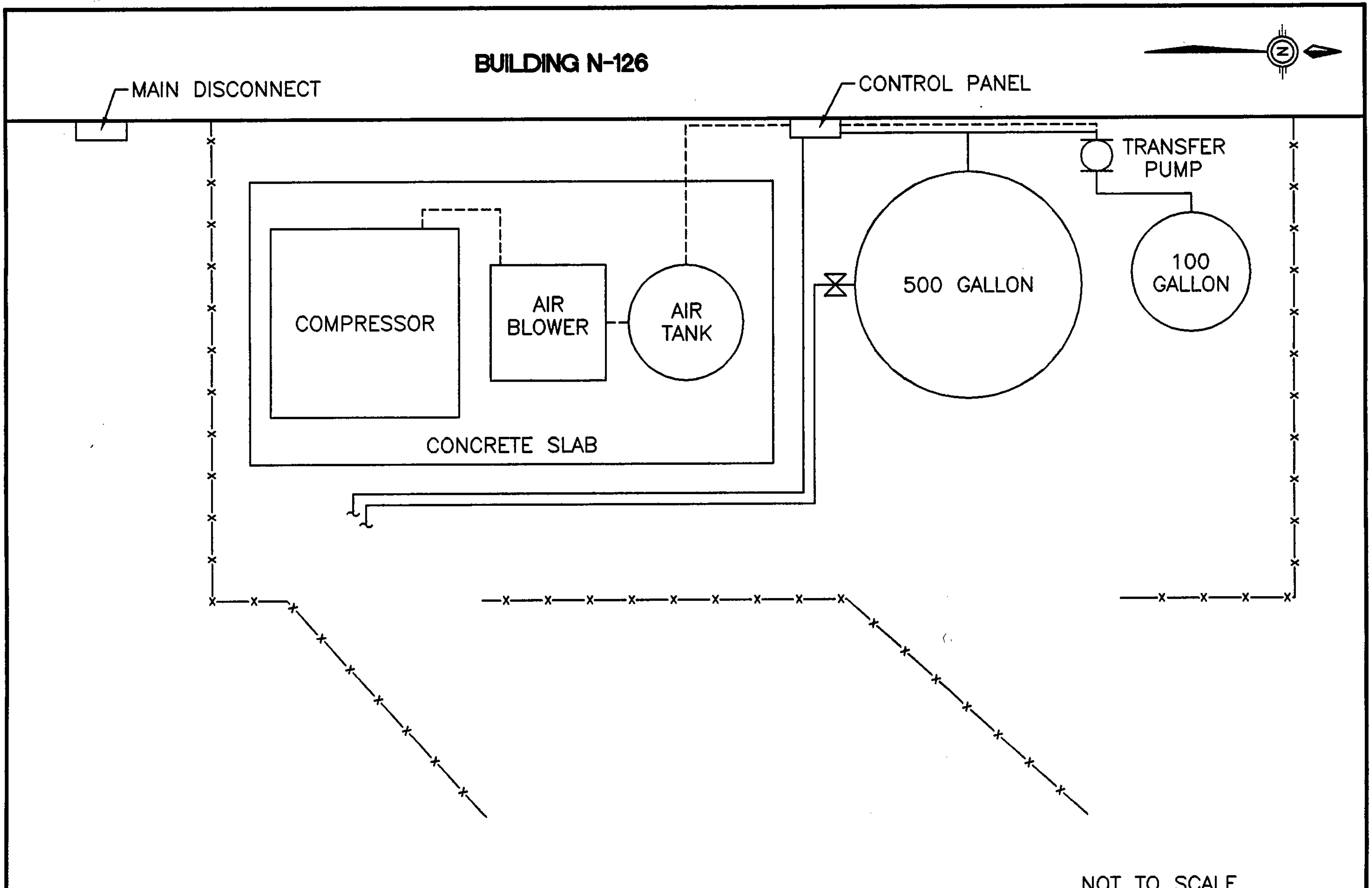
The 4-inch diameter PVC groundwater extraction well 007G57LF, which is screened in the fluvial deposits, was installed in December 1999. It is approximately 75 feet deep with a 30-foot-long, 0.02-inch slotted PVC screen from 42 to 72 feet bls. The well had a pneumatic submersible pump capable of pumping up to 7 gallons per minute (gpm), which was connected by a 3/4-inch hose to an aboveground chemical feed tank. Groundwater was pumped from this well to a 500-gallon aboveground holding tank or a 100-gallon chemical mixing tank.

### Groundwater Reinjection Wells

Groundwater from the extraction well was amended with nutrients and substrate in the aboveground system. Amended water was then reinjected by gravity flow into the aquifer via two 4-inch diameter PVC wells (007G60LF and 007G61LF) screened in the fluvial deposits which were installed in November/December 1999. They were approximately 75 feet deep and were screened with 0.02-inch slotted PVC screen, 30 feet long, from 45 to 75 feet bls.

### Treatability Study Monitoring Wells

In addition to the four existing monitoring wells (007G03LF, 007G04LF, 007G04UF, and 007G21LF), two 2-inch-diameter PVC wells (007G58LF and 007G59LF) were installed November 1999 to monitor the progress of the treatability system.



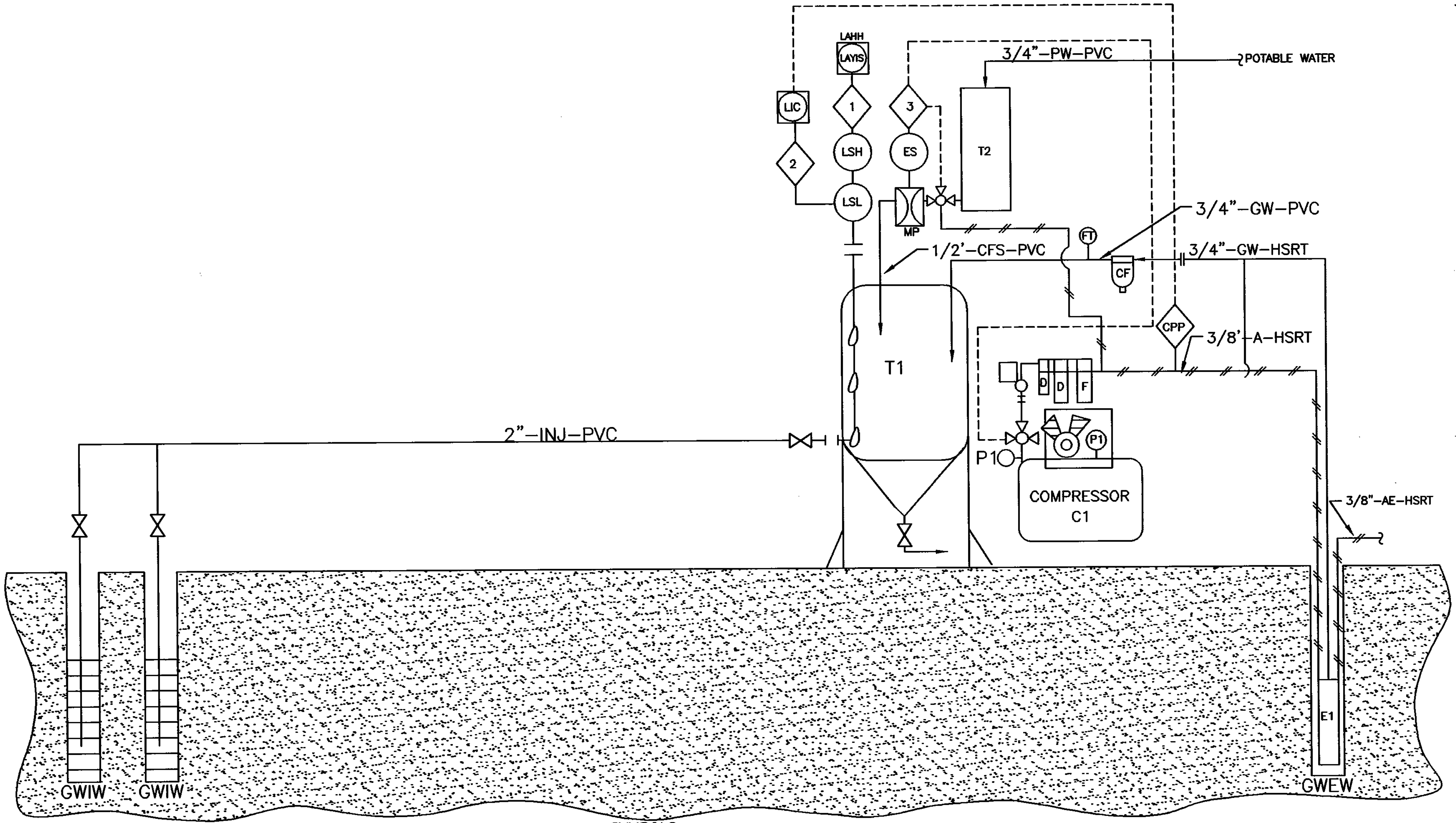

NOT TO SCALE

NOTES:
1) GREEN PRIVACY SLAT FENCING
2) FENCED AREA COVERED WITH CANOPY

NSA MID-SOUTH AOC A
A-A SEQUENTIAL
REMEDIATION TREATABILITY
STUDY REPORT

FIGURE 5-1
EQUIPMENT LAYOUT

DWG DATE: 07/02/01 | NAME: 0094001G002




## LEGEND

EQ. NO. T1
TITLE – GROUNDWATER RECEIVING TANK
TYPE – OPEN TOP CONICAL WITH REMOVABLE COVER, 2" DRAIN (FLANGED)
MATERIAL – FIBER GLASS OR POLYPROPYLENE
SIZE – 500 GALLONS
TEMP – AMB.
PRESS. – ATMOS.

EQ. NO. T2
TITLE – CARBON FEED TANK
TYPE – OPEN TOP WITH COVER (CYLINDRICAL) 1/2" DRAIN FLANGED
MATERIAL – POLYETHYLENE
SIZE – 100 GALLONS
TEMP – AMB.
PRESS. – ATMOS.

EQ. NO. C1
TITLE – RECIPROCATING AIR COMPRESSOR
TYPE – STANDARD ELECTRIC – HORIZONTAL 17 CFM, 5 HP, RECIPROCATING PISTON TYPE
TANK CAPACITY – 80 GALLONS
PRESSURE – MAX. 125 PSI

EQ. NO. E1
TITLE – DOWN-WELL (SUBMERSIBLE) AUTO PUMP (PNEUMATIC)
TYPE – AIR DISPLACEMENT CEE AP-4 OR EQUAL WITH AUTO CONTROL
MATERIAL – STAINLESS STEEL
CAPACITY – 7 GPM AT 35' HEAD.
PRESS – ATMOS
TEMP – AMB.

### INTERLOCK DESIGNATIONS

1 – ON HIGH LEVEL IN HOLDING TANK (T1) STOP ALL GROUNDWATER EXTRACTION WELL PUMPS (E1)
2 – ON LOW LEVEL IN HOLDING TANK (T1) START ALL GROUNDWATER EXTRACTION WELL PUMPS (E1)
3 – CARBON FEED PUMP OPERATES WITH GROUNDWATER PUMPS

### EQUIPMENT DESIGNATION

T1 – GROUNDWATER RECEIVING TANK
T2 – CARBON FEED TANK
E1 – PNEUMATIC SUBMERSIBLE PUMP
C1 – AIR COMPRESSOR

### LINE LEGEND

———— – PROCESS LINE
—+|—+|— – PNEUMATIC LINE
- - - - - – ELECTRICAL

### SYMBOLS

MP – METERING PUMP
FT – FLOW TOTALIZER
M – MANOMETER
FM – FLOW METER
⋈ – BUTTERFLY VALVE
|| – FLANGE
– CONTROL VALVE
– AIR FILTER/PRESSURE REGULATOR
GWEW – GROUNDWATER EXTRACTION WELL
GWIW – GROUNDWATER INJECTION WELL
PI – PRESSURE GAUGE 0-'74 PSI
LSL – LIQUID SWITCH LOW LEVEL
LSH – LIQUID SWITCH HIGH LEVEL
ES – ELECTRIC SWITCH
LAHH – LIQUID ALARM HIGH-HIGH
LIC – LIQUID INDICATOR CONTROLLER
CPP – CONTROL PANEL PUMPS
O – OIL RESERVOIR
D – DESICANT
F – FILTER
CF – CARTRIDGE FILTER

### TYPICAL LINE NUMBER

2"-BZ-CS

PIPE SIZE
SERVICE DESIGNATION
PIPING MATERIAL

### PIPING SERVICE DESIGNATION

A – AIR
GW – GROUNDWATER
CFS – CARBON FEED
INJ – INJECTION
AE – AIR EXHAUST
PW – POTABLE WATER

### PIPING MATERIAL DESIGNATION

PVC – POLYVINYL CHLORIDE
HSRT – HIGH STRENGTH REINFORCED TUBING.

NOT TO SCALE

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A-A SEQUENTIAL REMEDIATION TREATABILITY STUDY REPORT

FIGURE 5-2
PROCESS AND INSTRUMENTATION DIAGRAM

DWG DATE:05/14/02 | NAME: 0094001B001

They were approximately 75 feet deep and screened in the fluvial deposits from 42 to 72 feet bgs with 0.02-inch slotted PVC screen. In August 2000, two additional 2-inch-diameter PVC wells (007G62LF and 007G63LF) were installed with the same specifications as the other monitoring wells installed in November 1999 (see Appendix A).

All new monitoring wells were sampled from two depth intervals. The last character of the sample identification denotes the interval sampled, "A" for the upper part of the fluvial deposits (47 feet from the top of casing) or "B" for the lower part of the fluvial deposits (5 feet from the bottom of the well).

**Well Specifications**

All wells were installed in a boring drilled to a depth that targeted the base of the fluvial deposits. The wells are flush mounted at ground surface and have a well vault installed over the tops of the casings. The completed drill holes had outer diameters of 8 to 12 inches, and were large enough to accommodate a 2- or 4-inch ID well screen and standpipe.

After installation, the wells were thoroughly developed by the drill crew for at least 2 hours each, using a combination of pumping, surging, and flushing with potable water. All investigation-derived waste (IDW) from drilling and developing the wells were managed as hazardous waste. Development was completed when the onsite engineer or geologist judged the well to produce clear water and to be hydraulically responsive.

**Submersible Pump**

The air-operated submersible pump placed in the extraction well was a Clean Environmental Equipment (CEE) Standard AP-4 pump that could extract 7 gpm against a total head of 35 feet. The air supply was regulated by a controller-less total auto pump system. Air requirements, supplied by the compressor system, were 90 pounds per square inch (psi). To prevent overflow of the 500-gallon holding tank, the autopump system was connected to a tank-full shut-off system that would block air supply to the submersible pumps if the holding tank became full. Air supply could also be turned on or off manually by check valves.

**Chemical Feed Pump**

An air-operated diaphragm pump was used to pump water from the 100-gallon chemical mixing tank to the 500-gallon holding tank. The air supply was regulated by the same pump system as that used for the submersible pump. The air supply could be turned on or off manually by check valves.

**Compressor System**

An electrically powered, rotary screw-type compressor supplied 125 psi that powered the submersible pumps and chemical-feed diaphragm pump. The three-phase electrical motor required 230/460 volts at 60 hertz. The compressor was equipped with an air-drying system to reduce buildup of condensation in the pressure tank.

**Groundwater Filter System**

A filter system was installed in mid-April to keep fine solids from entering the reinjection wells and thus clogging their screens. The filter system included a 10/20 micron, cartridge filter and a pressure gauge to indicate clogging. The filters were replaced weekly or when the pressure exceeded 15 psi.

**Equipment Housing**

The blower system, controllerless auto pump system, chemical-feed pump, compressor, air drying system, 500-gallon holding tank, and 100-gallon chemical mixing tank were housed in a fenced area with a canopy. The housing provided protection for the equipment and controlled access to the system.

**Groundwater Recirculation System**

The recirculation system was made up of the extraction well, submersible pump, filter system, 500-gallon holding tank, chemical-feed pump, 100-gallon chemical mixing tank, and reinjection wells. The 500-gallon polyethylene holding tank had an inlet at the top and a 4-inch outlet at the bottom. The inlet was connected to the groundwater extraction well via the 3/4-inch hose and a PVC pipe diverted the groundwater influent to the bottom of the tank to avoid aeration and possible volatilization of the VOCs. The outlet was connected to the reinjection wells by an underground PVC piping network system. Water from the holding tank flowed by gravity to the reinjection wells. The 100-gallon chemical mixing tank was adjacent to the 500-gallon holding tank. A 1-inch inlet at the top of the 100-gallon tank allowed groundwater from extraction well 007G57LF to be pumped into the tank where carbon and nutrients were mixed into the groundwater. A chemical-feed diaphragm pump was used to transfer the amended groundwater from the mixing tank into the holding tank.

## 5.2 Study Area

RFI results for the treatability study area at AOC A show that most of the chlorinated VOC contamination is concentrated in the lower part of the fluvial deposits. TCE is the most prevalent chlorinated solvent detected, followed by carbon tetrachloride and PCE. The highest concentration of any single chlorinated solvent was in a groundwater sample from well 007G04LF, northeast of Building N-126, where TCE was detected at 4,400 micrograms per liter ($\mu$g/L) during the March 25, 1999 RFI sampling event. Because of the high concentrations in the area of monitoring well 007G04LF, the pilot study focused on the plume in this area.

# 6.0 SUMMARY OF FIELD ACTIVITIES

## 6.1 System Augmentations

During the pilot study, groundwater was pumped from the extraction well (007G57LF) to the 500-gallon holding tank in the equipment area. Two to three times a week, groundwater from 007G57LF was diverted to the 100-gallon chemical feed tank. When this tank was full, nutrients were added and mixed with the groundwater in the 100-gallon tank. Table 6-1 shows the augmentation schedule.

**Table 6-1**
**Augmentation Schedule**
**(per 100 gallons of water)**

| Period | | | Carbon Source | | Nutrients | |
|---|---|---|---|---|---|---|
| **Start** | **End** | **Days** | **Type** | **Quantity (lb)** | **Type** | **Quantity (lb)** |
| 3/14/00 | 3/22/00 | 8 | fructose | 1.1 | ammonium phosphate | 0.11 |
| 3/22/00 | 4/5/00 | 14 | fructose | 2.2 | ammonium phosphate | 0.22 |
| 4/5/00 | 4/26/00 | 21 | fructose | 2.2 | ammonium phosphate | 0.22 |
| 4/26/00 | 6/26/00 | 61 | fructose | 1.1 | ammonium phosphate | 0.22 |
| 7/7/00 | 12/8/00 | 154 | sodium acetate | 25 | ammonium phosphate | 0.22 |

*Note:*
lb = pound

During the nine months of the study, 19.3 pounds (lbs) of fructose, 8.7 lbs of ammonium phosphate, and 620 lbs of sodium acetate were added to the system. Typically, 100-gallons of carbon and/or nutrient-enriched groundwater were pumped from the 100-gallon tank into the 500-gallon holding tank. The diaphragm pump was used to pump water from the 100-gallon tank to the 500-gallon tank. More than 1.5 million gallons of water were recirculated during the nine-month study at flow rates ranging from 2 to 10 gpm. As discussed in Section 7.3, well-screen clogging affected re-injection rates.

## 6.2 Field Monitoring

Groundwater wells in the test area were monitored for key field parameters such as pH, DO, ORP, and carbon dioxide ($CO_2$) to optimize system operation and assess the geochemical response of the treatability study during the evaluation process. Baseline field-monitoring data were collected a week before the system was turned on. Wells monitored for baseline field parameters included the extraction well, two reinjection wells, two treatability study monitoring wells, and four existing monitoring wells. After the system was turned on, field parameters were measured weekly for all wells except for the extraction and reinjection wells, which were measured monthly. Two additional monitoring wells (62LF and 63LF) were installed in August 2000. After eight months of system operation, field parameters were measured biweekly. The standard field meters, instruments, and test kits used to make these measurements were calibrated in accordance with the manufacturer's instructions. Measurements were recorded on field data monitoring sheets.

## 6.3 Monthly Groundwater Sampling

Groundwater samples were collected prior to start-up of the treatability study to obtain baseline chemical and biochemical data in the study area. The samples were also collected monthly during the treatability study to track decreases and changes in chlorinated-solvent concentrations and daughter-product formation and destruction. Samples were also collected to help estimate the nutrient supplementation required during the study. Samples were analyzed for the contaminants/parameters listed in Table 6-2.

**Table 6-2**
**Baseline Groundwater Sampling Protocol**

| Analyte | Analytical Method | Wells Sampled | Purpose/Remarks |
|---|---|---|---|
| VOCs | SW 8260 | Extraction, injection, and TS monitoring wells | The purpose of VOC sampling is to obtain starting concentrations and track decreases in contaminant concentrations during the TS |
| Metals | 6010/7000 | Extraction and TS monitoring wells (only newly-installed MW) | To examine clogging or solubilization effects on metals such as iron and manganese as a result of the created anaerobic-aerobic zone. |
| **Biological and Geochemical Parameters** | | | |
| Total Kjeldahl Nitrogen | 351.1 - 351.4 | Extraction, injection, and TS monitoring wells | Nitrogen, phosphorus and carbon measurements are required to estimate the amount and frequency of nutrient supplementation required to optimize microbial activity. Chloride is a good indicator parameter used to estimate the quantity of chlorinated solvents that have been degraded during the TS. |
| Ammonia-nitrogen | 350.1 | | |
| Total phosphorus | 365.4 | | |
| Orthophosphate | 365.2 - 365.3 | | |
| Nitrate-nitrogen | 352.1 | | |
| Total organic carbon | 415.1 | | |
| Chloride | 325.3 | | |
| Total heterotrophic counts | SM 9215B | | |

*Note:*
TS = treatability study

Table 6-3 lists the protocol for periodic groundwater sampling and analysis. Groundwater samples were collected from area wells and analyzed for chemical and biochemical data.

**Table 6-3**
**Periodic Groundwater Sampling Protocol**

| Analyte | Wells Sampled | Sampling Frequency |
|---|---|---|
| VOCs | Extraction and TS monitoring wells | Monthly until the conclusion of the study |
| Metals | Extraction and TS monitoring wells (only newly-installed MW) | After one month of treatability system operation |
| **Biological and Geochemical Parameters** | | |
| Total Kjeldahl Nitrogen | Extraction, injection, and TS monitoring wells | Monthly until the conclusion of the study |
| Ammonia-nitrogen | | |
| Total phosphorus | | |
| Orthophosphate | | |
| Nitrate-nitrogen | | |
| Total organic carbon | | |
| Chloride | | |
| Total heterotrophic counts | | |

*Note:*
TS = treatability study

## 6.4 Post-Shutdown Monitoring

After the system was shut down in December 2000, DO, pH, and ORP continued to be measured biweekly in samples from the wells to monitor changes in geochemistry in the aquifer. In March 2001, groundwater samples were collected from all the wells for VOC analysis. Post-shutdown monitoring was conducted to address the following:

- Will TCE concentrations rebound after the recirculation and amendment system is shutdown? If so, how long until concentrations increase?

- How long until the aquifer returns to pretreatment conditions?

- What happens to the *cis*-1,2-DCE that was generated from the reductive chlorination of TCE? Will persistent anaerobic condition result in *cis*-1,2-DCE degradation to VC? Conversely, is it possible that a return to aerobic conditions will foster *cis*-1,2-DCE degradation?

All sampling was performed in accordance with the Quality Assurance Project Plan (QAPP) and the Sampling and Analysis Program (SAP) developed as part of the RFI work plan for this site (E/A&H, 1994). Groundwater samples to be analyzed were sent to Laucks Testing Labs of Seattle, Washington, while groundwater samples for various gas analyses were sent to Microseeps of Pittsburgh, Pennsylvania.

# 7.0 RESULTS AND ANALYSIS

VOC (Section 7.1) , geochemistry (Section 7.2) , and hydraulic (Section 7.3) observations and results are discussed below.

## 7.1 VOC Analysis

Select VOC analytical results for the treatability study monitoring wells, extraction well, and reinjection wells are provided in Table 7-1. The table includes VOC data from the baseline sampling event, which was performed prior to the start of the treatability study, from nine subsequent events during the study (April to December), and from the post-shutdown event (March 2001). Only the VOCs of prime concern in the pilot study area, PCE, TCE, *cis*-1,2-DCE, and VC are included in this table. These data are also shown graphically in Appendix B.

Select phases of the A-A study are discussed below.

### 7.1.1 Early Concentration Fluctuations

Several significant TCE concentration fluctuations occurred during the first three months of A-A system operation. The first sampling event (April) after system startup indicated TCE concentrations in the extraction and two injection wells five to 30 times higher than baseline (March) results. Comparatively, the TCE concentrations at the four initial downgradient monitoring wells (007G58LFA, 007G58LFB, 007G59LFA, and 007G59LFB) were elevated in March (210 to 2,100 $\mu$g/L), substantially reduced in April (44 to 94 $\mu$g/L), and elevated again in May (190 to 1,200 $\mu$g/L).

**Table 7-1**
**A-A Pilot Study Results (μg/L)**

| Well ID | Parameter | Baseline | A-A Operation | | | | | | | | | Post-Shutdown |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3/00 | 4/00 | 5/00 | 6/00 | 7/00 | 8/00 | 9/00 | 10/00 | 11/00 | 12/00 | 3/01 |
| **007G03LF** upgradient monitoring well | PCE | 47 | 41 | 51 | 66 | 91 | 110 | 140 | 130 | 150 | 120 | 73 |
| | TCE | 26 | 17 | 18 | 16 | 14 | 16 | 18 | 17 | 15 | 14 | 12 |
| | *cis*-1,2-DCE | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| | VC | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| **007G57LF** extraction well | PCE | 7 | 9 | 45 | 97 | 70 J | 68 | 52 | 44 | 39 | 38 | 45 |
| | TCE | 160 | 2,400 D | 4,400 D | 3,100 D | 2,300 | 2,500 D | 2,300 D | 1,400 D | 1,500 D | 1,000 D | 1,600 D |
| | *cis*-1,2-DCE | 2 J | 4 | 11 | 12 | <150 | 12 | 10 | 14 | 24 | 42 | 83 |
| | VC | <3 | <3 | <3 | <3 | <150 | <3 | <3 | <3 | <3 | <3 | <3 |
| **007G60LF** injection well | PCE | 50 | 7 | 30 | 53 | 66 | 54 | 48 | NS | NS | 28 | <3 |
| | TCE | 66 | 2,200 D | 3,000 D | 2,300 D | 2,100 | 1,900 D | 1,800 D | NS | NS | 1,300 D | 2 J |
| | *cis*-1,2-DCE | <3 | 4 | 7.7 | 8 | <60 | 11 | 22 | NS | NS | 54 | 2 J |
| | VC | <3 | <3 | <3 | <3 | <60 | <3 | <3 | NS | NS | <3 | 540 D |
| **007G61LF** injection well | PCE | 41 | 6 J | 35 | 50 | 75 | 55 | 47 | NS | NS | 30 | <3 |
| | TCE | 300 D | 1,600 D | 3,400 D | 2,300 D | 2,200 | 1,900 D | 1,800 D | NS | NS | 1,400 D | <3 |
| | *cis*-1,2-DCE | 4 | 5 J | 8.3 | 7 | <60 | 11 | 17 | NS | NS | 57 | <3 |
| | VC | <3 | <6 | <3 | <3 | <60 | <3 | <3 | NS | NS | <3 | 480 D |

**Table 7-1**
**A-A Pilot Study Results (μg/L)**

| Well ID | Parameter | Baseline | A-A Operation | | | | | | | | | Post-Shutdown |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3/00 | 4/00 | 5/00 | 6/00 | 7/00 | 8/00 | 9/00 | 10/00 | 11/00 | 12/00 | 3/01 |
| **007G62LFA** intermediate monitoring well | PCE | NA | NA | NA | NA | NA | 22 | 14 | 10 | 6 | <3 | <3 |
| | TCE | NA | NA | NA | NA | NA | 700 D | 360 D | 250 D | 150 | 2 J | 22 |
| | *cis*-1,2-DCE | NA | NA | NA | NA | NA | 940 D | 990 D | 1,100 D | 1,100 D | 1,100 D | 990 D |
| | VC | NA | NA | NA | NA | NA | <3 | <3 | <3 | <3 | <3 | 81 |
| **007G62LFB** intermediate monitoring well | PCE | NA | NA | NA | NA | NA | 28 | 16 | 9 | 7 | <3 | <3 |
| | TCE | NA | NA | NA | NA | NA | 820 D | 460 D | 270 D | 190 | 5 | <3 |
| | *cis*-1,2-DCE | NA | NA | NA | NA | NA | 880 D | 990 D | 1,000 D | 1,100 D | 1,100 D | 1,000 D |
| | VC | NA | NA | NA | NA | NA | <3 | <3 | <3 | <3 | <3 | 92 |
| **007G63LFA** intermediate monitoring well | PCE | NA | NA | NA | NA | NA | 50 | 45 | 38 | 35 | 19 | <3 |
| | TCE | NA | NA | NA | NA | NA | 1,800 D | 1,600 D | 1,300 D | 1,200 D | 530 D | 10 |
| | *cis*-1,2-DCE | NA | NA | NA | NA | NA | 22 | 140 | 110 | 270 D | 560 D | 1,000 D |
| | VC | NA | NA | NA | NA | NA | <3 | <3 | <3 | <3 | <3 | <3 |
| **007G63LFB** intermediate monitoring well | PCE | NA | NA | NA | NA | NA | 53 | 44 | 38 | 33 | 21 | <3 |
| | TCE | NA | NA | NA | NA | NA | 1,700 D | 1,600D | 1,300 D | 1,200 D | 560 D | <3 |
| | *cis*-1,2-DCE | NA | NA | NA | NA | NA | 43 | 150 | 140 | 240 D | 520 D | 1,200 D |
| | VC | NA | NA | NA | NA | NA | <3 | <3 | <3 | <3 | <3 | 4 |

**Table 7-1**
**A-A Pilot Study Results (μg/L)**

| Well ID | Parameter | Baseline | A-A Operation | | | | | | | | | Post-Shutdown |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3/00 | 4/00 | 5/00 | 6/00 | 7/00 | 8/00 | 9/00 | 10/00 | 11/00 | 12/00 | 3/01 |
| **007G58LFA** intermediate monitoring well | PCE | 9 | 1 J | 4.8 | 19 | 55 J | 53 | 41 | 22 | 15 | 10 | 34 |
| | TCE | 740 D | 77 | 920 D | 1,800 D | 2700 | 2,300 D | 1,700 D | 800 D | 710 D | 370 D | 1,300 D |
| | *cis*-1,2-DCE | 5 | <3 | 2.1 J | 4 | <60 | 11 | <3 | 620 D | 840 D | 810 D | 150 D |
| | VC | <3 | <3 | <3 | <3 | <60 | <3 | <3 | <3 | <3 | <3 | <3 |
| **007G58LFB** intermediate monitoring well | PCE | 3 | 1 J | 6.5 | 21 | 63 | 59 | 39 | 13 | 5 | 7 | 32 |
| | TCE | 210 D | 69 | 1,200 D | 2,000 D | 2,600 | 2,500 D | 1,500 D | 400 D | 140 | 170 | 1,300 D |
| | *cis*-1,2-DCE | 2 J | <3 | 2.7 J | 5 | <60 | 13 | 610 D | 930 D | 1,300 D | 1,000 D | 170 |
| | VC | <3 | <3 | <3 | <3 | <60 | <3 | <3 | <3 | <3 | <3 | <3 |
| **007G59LFA** intermediate monitoring well | PCE | 20 | 5 | 3.1 | 18 | <60 | 35 | 49 | 34 | 24 | 12 | 29 |
| | TCE | 2,100 D | 94 | 190 D | 1,700 D | 2,000 | 1,900 D | 2,100 D | 1,200 D | 960 D | 570 D | 910 D |
| | *cis*-1,2-DCE | 18 | 1 J | 1.1 J | 7 | <60 | 9 | 110 | 210 D | 450 D | 720 D | 320 D |
| | VC | <3 | <3 | <3 | <3 | <60 | <3 | <3 | <3 | <3 | <3 | <3 |
| **007G59LFB** intermediate monitoring well | PCE | 11 | 3 J | 4.2 | 18 | 46 J | 55 | 43 | 33 | 19 | 8 | 25 |
| | TCE | 1,600 D | 44 | 560 D | 1,800 D | 2,400 | 2,500 D | 1,700 D | 1,100 D | 850 D | 370 D | 920 D |
| | *cis*-1,2-DCE | 14 | <3 | 2 J | 6 | <60 | 11 | 230 D | 360 D | 620 D | 880 D | 450 D |
| | VC | <3 | <3 | <3 | <3 | <60 | <3 | <3 | <3 | <3 | <3 | 1 J |

**Table 7-1**
**A-A Pilot Study Results ($\mu$g/L)**

| Well ID | Parameter | Baseline | A-A Operation | | | | | | | | | Post-Shutdown |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3/00 | 4/00 | 5/00 | 6/00 | 7/00 | 8/00 | 9/00 | 10/00 | 11/00 | 12/00 | 3/01 |
| **007G04LF** intermediate monitoring well | PCE | 17 | 110 | 5.2 | 10 | 35 J | 38 | 49 | 35 | 27 | <3 | 22 |
| | TCE | 2,000 D | 1,800 D | 240 D | 1,200 D | 2,400 | 2,400 D | 2,300 D | 1,400 D | 1,100 D | 3 J | 930 D |
| | *cis*-1,2-DCE | 2 J | 2 J | 1 J | 3 J | <60 | 12 | 36 | 260 D | 540 D | <3 | 260 D |
| | VC | <3 | <3 | <3 | <3 | <60 | <3 | <3 | <3 | <3 | <3 | <3 |
| **007G04UF** intermediate monitoring well | PCE | <3 | <3 | <3 | 2 J | <3 | <3 | <3 | 9 | 4 | 15 | <3 |
| | TCE | 2 J | 1 J | 190 D | 590 D | 15 | 130 | 74 | 400 D | 160 | 800 D | 1 J |
| | *cis*-1,2-DCE | <3 | <3 | 5.7 | 15 | <3 | 3 J | 2 J | 8 | 4 | 580 D | <3 |
| | VC | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| **007G21LF** downgradient monitoring well | PCE | 6 | 6 | 6.4 | 5 | 7 | 6 | 8 | NS | NS | 9 | 12 |
| | TCE | 26 | 27 | 26 | 21 | 25 | 26 | 31 | NS | NS | 43 | 52 |
| | *cis*-1,2-DCE | <3 | <3 | <3 | <3 | <3 | <3 | <3 | NS | NS | 1 J | <3 |
| | VC | <3 | <3 | <3 | <3 | <3 | <3 | <3 | NS | NS | <3 | <3 |

*Notes:*
D = A secondary dilution was used to analyze the sample.
J = Estimated value.
NA = not applicable (wells not installed until August 2000).
NS = not sampled.

The TCE concentration fluctuations are likely attributed to hydraulic effects from the startup of the recirculation system. Groundwater with relatively high TCE concentrations was drawn to the extraction well during system operation. This TCE-contaminated groundwater was eventually extracted and the re-injected into wells 007G60LF and 007G61LF, which resulted in the significant concentration increase at those locations. The downgradient monitoring wells also exhibited concentration changes because of the pumping-enhanced movement of TCE in the subsurface. Biological induced changes did not likely occur until later in the evaluation (August).

### 7.1.2 PCE and TCE Reduction and Formation of Daughter Products

The pumping-induced TCE concentration fluctuations seemingly stabilized by June. Injection well TCE concentrations were consistent with extraction well water quality. Though indicating hydraulic stabilization, downgradient well (007G58LF and 007G59LF) sampling results from June, July, and August also suggested minimal impact from the A-A system. In response, the carbon source was switched from fructose to acetate in June in an effort to accelerate the development of anaerobic conditions. When little impact was observed in July, two additional monitoring wells (007G62LF and 007G63LF) were installed closer to the injection wells to evaluate whether TCE reduction was actually occurring closer to the injection wells and had not yet impacted the wells that were further downgradient.

August sampling results from the new wells indicated elevated levels of *cis*-1,2-DCE (particularly in 007G62LF), which is a common biological daughter product of PCE and TCE reductive dechlorination. Because *cis*-1,2-DCE concentrations were very low before the evaluation was started, its significant increase in the aquifer indicates that the amendments (fructose/acetate and ammonium phosphate) effectively triggered reductive dechlorination. Moreover, *cis*-1,2-DCE concentrations remained low at background well 007G3LF and (considerably) downgradient well 21LF, further confirming that it was the augmentation that induced its formation. In addition, *cis*-1,2-DCE development during the study also shows that the fluvial aquifer does possess the required consortia of microorganisms to reduce PCE and TCE under the appropriate geochemical conditions.

Because wells 007G62LF and 007G63LF were installed after the carbon source was changed from fructose to acetate, it was difficult to evaluate whether fructose is an adequate amendment. If the newest monitoring wells had been installed at the beginning of the study, it is possible that PCE and TCE reduction would have been observed earlier and fructose would have remained the carbon source of choice. Because of time constraints, carbon source selection and treatment time were not evaluated independently.

From August through system shutdown in December, all four downgradient monitoring wells (007G58LF, 007G59LF, 007G62LF, and 007G63LF) exhibited substantial PCE and TCE concentration decreases and simultaneous *cis*-1,2-DCE increases. Though an order of magnitude lower in concentration than TCE, PCE concentrations also discernibly deceased during the study. Also, there did not appear to be any significant differences in concentrations between groundwater in the upper and lower portions of the fluvial deposits.

Before reductive dechlorination occurred in the latter half of the evaluation, there was a period from May through July in which carbon in the form of fructose and sodium acetate was depleting the natural oxygen via microbial activity. Following oxygen depletion, the groundwater system gradually developed the appropriate biochemical environment, which included a microbial acclimation process to degrade chlorinated solvents.

While the formation of *cis*-1,2-DCE is an excellent indicator that the aquifer became anaerobic and was able to sustain reductive dechlorination of PCE and TCE, the data also suggest that this intermediate compound did not degrade as quickly as it was being formed under the treatability-study conditions. As the study progressed, *cis*-1,2-DCE began appearing further downgradient in the study area as it was detected at significant concentrations at well 007G04LF.

As such, the redox state of groundwater in the aquifer may not have been low enough for the continued reductive dechlorination of *cis*-1,2-DCE to VC during the recirculation phase of the study. Again, *cis*-1,2-DCE can also degrade aerobically or cometabolically, but because the study area was devoid of dissolved oxygen, this pathway was not likely. Finally, it is also possible that *cis*-1,2-DCE degradation requires the acclimation of a consortia of microorganisms different from those that degrade PCE and TCE. The buildup of these microorganisms may include a lag period, which was not established in the aquifer during the pilot study.

VC was not detected in the aquifer in the treatability area wells during the recirculation phase of the study because it was either not being created or was degrading very quickly upon formation. VC is known to degrade under aerobic and anaerobic conditions. For this particular application, VC can be anaerobically oxidized by native microorganisms capable of using ferrous iron as the electron acceptor. In anaerobic aquifers with relatively high concentrations of natural iron ($>1$ mg/L) (see Table 7-2), VC could degrade upon being formed via reductive dechlorination.

Though it is conceivable that VC was being degraded upon formation via iron-mediated metabolic activity, it is more likely that no VC was ever formed during the recirculation phase of the study.

**Table 7-2**
**Iron Concentrations (μg/L)**

| **Well** | **Sample Date** | |
|---|---|---|
| | **3/6/00** | **4/12/00** |
| 007G57LF | 5,020 | 3,220 |
| 007G58LFA | 1,570 | 1,620 |
| 007G58LFB | 3,260 | 1,640 |

### 7.1.3 Post-Shutdown Monitoring

After the system was shut down in December 2000, DO, pH, and ORP continued to be measured biweekly in samples from the wells to monitor changes in geochemistry in the aquifer. In March 2001, groundwater samples were collected from all the wells for VOC analysis. As discussed in Section 6.4, post-shutdown was conducted to address TCE rebounding, the fate of *cis*-1,2-DCE, and aquifer re-aeration.

There were several interesting results three months after the extraction-re-injection system was stopped. Post-shutdown results for the extraction well indicated increased TCE and *cis*-1,2-DCE concentrations. The apparent TCE increase could be attributed to an anomalously low TCE concentration December (October, November, December, and March data were 1,400, 1,500, *1,000,* and 1,600 μg/L respectively). However, the *cis*-1,2-DCE increase is consistent with its gradual increase since August. Without a concomitant TCE decrease at this well, this could be evidence that *cis*-1,2-DCE is forming upgradient of and migrating to the extraction well.

Stopping the recirculation system and slowly returning the aquifer to natural hydraulic conditions resulted in a relatively stagnant environment, particularly near the injection wells (60LF and 007G61LF) and first row of monitoring wells (007G62LF and 007G63LF). This stagnancy coupled with ample[1] residual organic carbon in the groundwater resulted in much stronger anaerobic conditions resulting in *cis*-1,2-DCE degradation to VC (up to 540 $\mu$g/L in 007G60LF). Consistent with the analytical results, ORP measurements taken from the injection wells have ranged from -150 to -200 mV since system shutdown, likely low enough for *cis*-1,2-DCE and VC degradation. Moving from the injection wells to the extraction well in the direction of groundwater flow, ORP measurements are increasingly more positive and the quantity of contaminant mass increases.

Though speculative as of March 2001, continued post-shutdown monitoring would be conducted to further assess the following:

1. Sufficiently anaerobic conditions can be generated in the lower fluvial aquifer to promote complete chlorinated VOC mineralization. If not, a return to natural aerobic conditions would likely stimulate the degradation of *cis*-1,2-DCE and VC.

2. Indigenous microbes capable of degrading *cis*-1,2-DCE and VC are present.

3. With some TCE mass now reduced to *cis*-1,2-DCE or VC, further degradation will likely occur in either sustained anaerobic or naturally re-aerated pre-treatment conditions. Continued monitoring will demonstrate whether intrinsic aerobic conditions can sustain biodegradation or sparging/natural aerobic conditions are required to complete the treatment process.

[1] Compared with pre-shutdown samples, TOC concentrations in samples from the injection wells and 007G62LF and 007G63LF monitoring wells were one to two orders of magnitude higher after the system was shut down.

### 7.1.4 Degradation Rates

Microbial kinetics are generally dependent on several factors:

- microbial growth and populations
- starting concentrations
- availability of carbon sources and nutrients,
- degradation occurring due to attached-phase and suspended-phase microorganisms.

The zero-order degradation rate equation used to calculate contaminant degradation rates is:

$$C_t = C_0 - kt$$

**Where:**
$C_t$ = Solute (TCE) concentration in mg/L at time t
$C_0$ = Solute (TCE) concentration in mg/L at time "zero" (in this case, August)
t = time (days)
k = first-order degradation rate in $day^{-1}$ (1/day)

Comparatively, the first-order degradation rate equation, which commonly represents TCE degradation kinetics, used to calculate contaminant degradation rates is:

$$C_t = C_0 e^{-kt}$$

PCE and TCE degradation rates for the purpose of estimating clean-up times and scale-up factors were estimated for the two closest monitoring wells (007G62LF and 007G63LF) using August, September, October, November, and March VOC results. The December data were considered anomalous and not included the assessment.

The data were plotted arithmetically and logarithmically for each of the wells to estimate the overall zero- or first-order degradation rate, which accounts for both biological and physical (i.e., dispersion, adsorption, volatilization, and dilution) degradation mechanisms. The graphs for each of the wells are provided in Appendix C. The results of the degradation rate assessment are summarized in Table 7-3.

**Table 7-3**
**Degradation Rate Estimation Summary**

| Well | VOC | Type | 8/22/00<br>0 | 9/21/00<br>30 | 10/18/00<br>57 | 11/14/00<br>84 | 3/27/01<br>217 | $R^2$ | k | O |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Date/Day** | | | | | | | |
| 007G62LFA | TCE | Meas. | 700 D | 360 D | 250 D | 150 | 22 | 0.995 | -0.016 | 1 |
| | | *Model* | *700* | *439* | *288* | *189* | *24* | | | |
| | PCE | Meas. | 22 | 14 | 10 | 6 | <3 | 0.921 | -0.009 | 1 |
| | | *Model* | *22* | *17* | *13* | *10* | *<3* | | | |
| 007G62LFB | TCE | Meas. | 820 D | 460 D | 270 D | 190 | <3 | 0.983 | -0.026 | 1 |
| | | *Model* | *820* | *373* | *183* | *90* | *<3* | | | |
| | PCE | Meas. | 28 | 16 | 9 | 7 | <3 | 0.905 | -0.010 | 1 |
| | | *Model* | *28* | *21* | *16* | *13* | *<3* | | | |
| 007G63LFA | TCE | Meas. | 1,800 D | 1,600 D | 1,300 D | 1,200 D | 10 | 0.995 | -8.286 | 0 |
| | | *Model* | *1800* | *1551* | *1328* | *1104* | *2J* | | | |
| | PCE | Meas. | 50 | 45 | 38 | 35 | <3 | 0.995 | -0.219 | 0 |
| | | *Model* | *50* | *43* | *38* | *32* | *<3* | | | |
| 007G63LFB | TCE | Meas. | 1,700 D | 1,600 D | 1,300 D | 1,200 D | 3 | 0.989 | -8.045 | 0 |
| | | *Model* | *1700* | *1459* | *1241* | *1024* | *-46* | | | |
| | PCE | Meas. | 53 | 44 | 38 | 33 | 3 | 0.998 | -0.226 | 0 |
| | | *Model* | *53* | *46* | *40* | *34* | *4* | | | |

*Notes:*
D = A secondary dilution was used to analyze the sample.
J = Estimated value.
$R^2$ = R-squared value
k = degradation rate constant (1/day)
O = order of the reaction

Interestingly, PCE and TCE degradation rates for well 007G62LF are represented by first-order kinetics while 007G63LF is represented by zero-order kinetics. The difference between the two wells is likely due to starting concentrations. PCE and TCE concentrations at well 007G63LF are approximately twice those at 007G62LF.

**PCE**

Zero-order rates for PCE ranged from 0.219 $day^{-1}$ (80 $yr^{-1}$) to 0.226 $day^{-1}$ (83 $yr^{-1}$). First-order rates for PCE ranged from 0.009 $day^{-1}$ (3.3 $yr^{-1}$) to 0.010 $day^{-1}$ (3.7 $yr^{-1}$). As shown in Table 7-4, first-order PCE degradation rates from the A-A pilot study are reasonably consistent with other enhanced bioremediation evaluations.

**Table 7-4**
**PCE Degradation Rate Summary**

| Source | Degradation Rates | | | Comments |
|---|---|---|---|---|
| | $Day^{-1}$ | $Year^{-1}$ | Half-Life (days) | |
| A-A Study | 0.009 - 0.01 | 3.3 - 3.7 | 69 - 77 | |
| Sheldon, 1999 | 0.005 - 0.011 | 2.0 - 3.8 | 66 - 128 | rates decreased as HRC was depleted |
| Dooley, 1999 | 0.021 | 7.7 | 33 | rate order not reported (assumed first) |
| Maierle, 2001 | 0.021 - 0.027 | 7.7 - 9.5 | 25.7 - 33 | enhanced reductive dechlorination (ERD) |

**TCE**

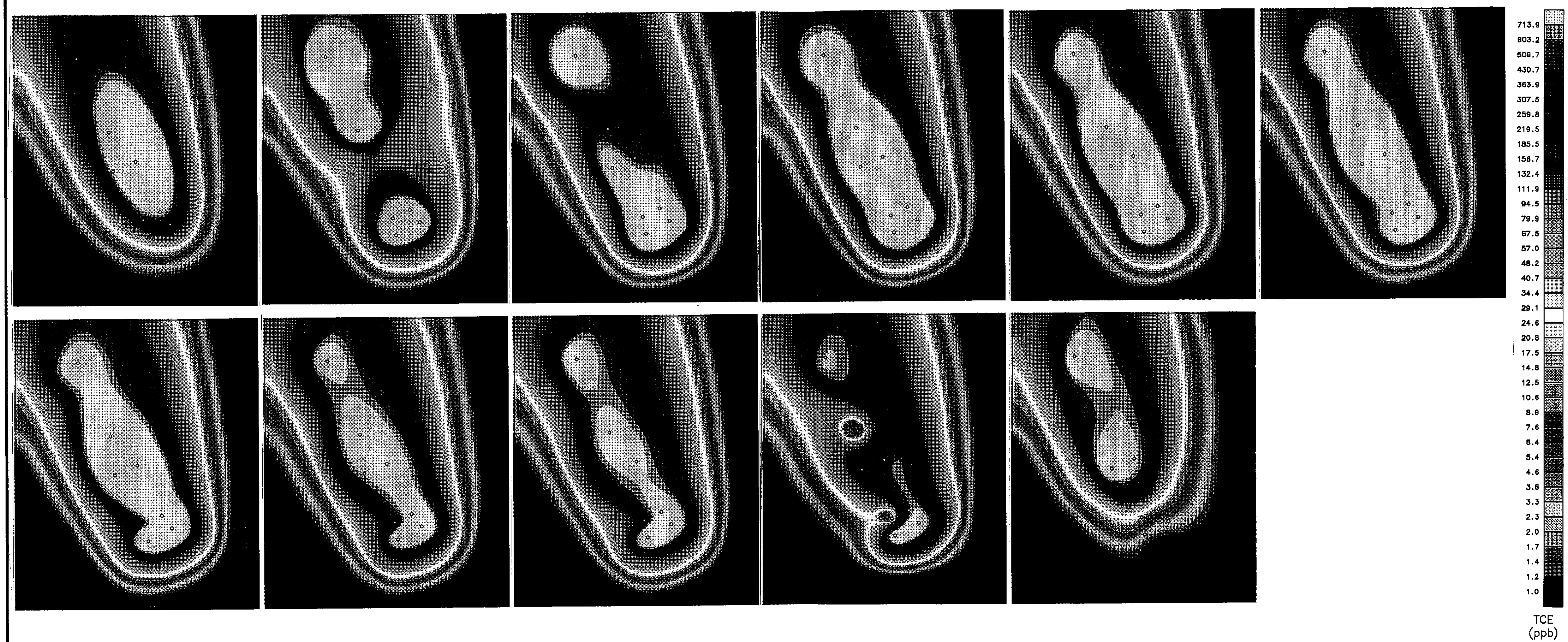
Zero-order rates for TCE ranged from 8.05 $day^{-1}$ (2,940 $yr^{-1}$) to 8.29 $day^{-1}$ (3,025 $yr^{-1}$). First-order rates for TCE ranged from 0.016 $day^{-1}$ (5.8 $yr^{-1}$) to 0.026 $day^{-1}$ (9.5 $yr^{-1}$). As shown in Table 7-5, first-order TCE degradation rates from the A-A pilot study are reasonably consistent with other enhanced bioremediation evaluations. Further, the higher estimated first-order value is about an order of magnitude greater than the reported literature value of natural attenuation studies at monitored natural attenuation (MNA) sites; the lower estimated value is five times higher. The degradation rate comparison indicates that the site is very amenable to microbial enhancement.

**Table 7-5**
**TCE Degradation Rate Summary**

| Source | Degradation Rates: Day$^{-1}$ | Year$^{-1}$ | Half-Life (days) | Comments |
|---|---|---|---|---|
| **Enhanced In Situ Bioremediation** | | | | |
| A-A Study | 0.016 - 0.026 | 5.8 - 9.5 | 26.7 - 43.3 | |
| Dooley, 1999 | 0.018 | 6.6 | 38.5 | rate order not reported |
| Maierle, 2001 | 0.005 - 0.023 | 1.8 - 8.4 | 30.1 - 138.6 | enhanced reductive dechlorination (ERD) |
| **MNA** | | | | |
| Cox, 1995 | 0.003 | 1.1 | 231 | sequential anaerobic-aerobic aquifer |
| Lee, 1995 | 0.002 | 0.7 | 347 | downgradient of an industrial landfill |

### 7.1.5 TCE Mass Degradation Estimation

This section is a preliminary effort at estimating the mass of TCE that was degraded as a result of the treatability study. Contours were drawn to estimate the affected area using TCE concentrations in the fluvial deposit wells in the study area. Rather than relying on the data from the beginning and end of the study because of pumping-induced fluctuations, concentration contours were generated for all 11 sampling events (baseline, nine months of operation, and one shut-down event) to evaluate TCE mass changes over time. The concentration contours for each month are shown in Figure 7-1.




Naval Facilities Engineering Command • Southern Division •

FIGURE 7–1
MONTHLY TCE PLUMES
A–A SEQUENTIAL STUDY TREATABILITY REPORT
AOC A – NORTHSIDE FLUVIAL GROUNDWATER
NSA MID–SOUTH, MILLINGTON, TN

Then, for simplicity, the 5, 100, and 1,000 $\mu$g/L contours were used to generate TCE mass estimates for each month during the study. The area within each of the three contour intervals was multiplied by an assumed saturated thickness (40 feet), porosity (25%), and average concentration within the contour to calculate the mass of TCE for each month. The results are summarized in Table 7-6. TCE mass trends are presented graphically in Figures 7-2a and b.

**Table 7-6**
**TCE Mass Estimation Summary**

| ppb | Mar-00 | Apr-00 | May-00 | Jun-00 | Jul-00 | Aug-00 | Sep-00 | Oct-00 | Nov-00 | Dec-00 | Mar-01 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TCE Plume Area (square feet) | | | | | | | | | | | |
| 5 | 16,777 | 18,960 | 18,548 | 18,666 | 18,038 | 18,146 | 18,777 | 18,298 | 18,690 | 17,612 | 15,066 |
| 100 | 9,805 | 8,644 | 11,608 | 12,050 | 11,372 | 11,457 | 11,703 | 11,280 | 11,289 | 9,161 | 8,120 |
| 1,000 | 2,274 | 1,857 | 1,940 | 4,062 | 3,727 | 3,516 | 3,067 | 1,109 | 660 | 169 | 584 |
| TCE Mass (kg) | | | | | | | | | | | |
| 5 | 0.69 | 0.78 | 0.76 | 0.77 | 0.74 | 0.75 | 0.77 | 0.75 | 0.77 | 0.73 | 0.62 |
| 100 | 4.04 | 3.56 | 4.78 | 4.96 | 4.68 | 4.72 | 4.82 | 4.64 | 4.65 | 3.77 | 3.34 |
| 1,000 | 6.24 | 5.10 | 5.33 | 11.15 | 10.23 | 9.65 | 8.42 | 3.04 | 1.81 | 0.46 | 1.60 |
| **Total** | **10.97** | **9.44** | **10.87** | **16.88** | **15.65** | **15.12** | **14.01** | **8.44** | **7.23** | **4.96** | **5.57** |
| Percent Mass Change from Baseline (Mar-00) | | | | | | | | | | | |
| 5 | 100% | 113% | 111% | 111% | 108% | 108% | 112% | 109% | 111% | 105% | 90% |
| 100 | 100% | 88% | 118% | 123% | 116% | 117% | 119% | 115% | 115% | 93% | 83% |
| 1000 | 100% | 82% | 85% | 179% | 164% | 155% | 135% | 49% | 29% | 7% | 26% |
| **Total** | **100%** | **86%** | **99%** | **154%** | **143%** | **138%** | **128%** | **77%** | **66%** | **45%** | **51%** |

*Assumptions*
Aquifer thickness = 40 feet
Average concentration in 5 ppb contour = 30 ppb
Average concentration in 100 ppb contour = 300 ppb
Average concentration in 100 ppb contour = 2,000 ppb
Porosity = 0.25

**Figure 7-2a**
**AOC A Pilot Study TCE Plume Area Trends**

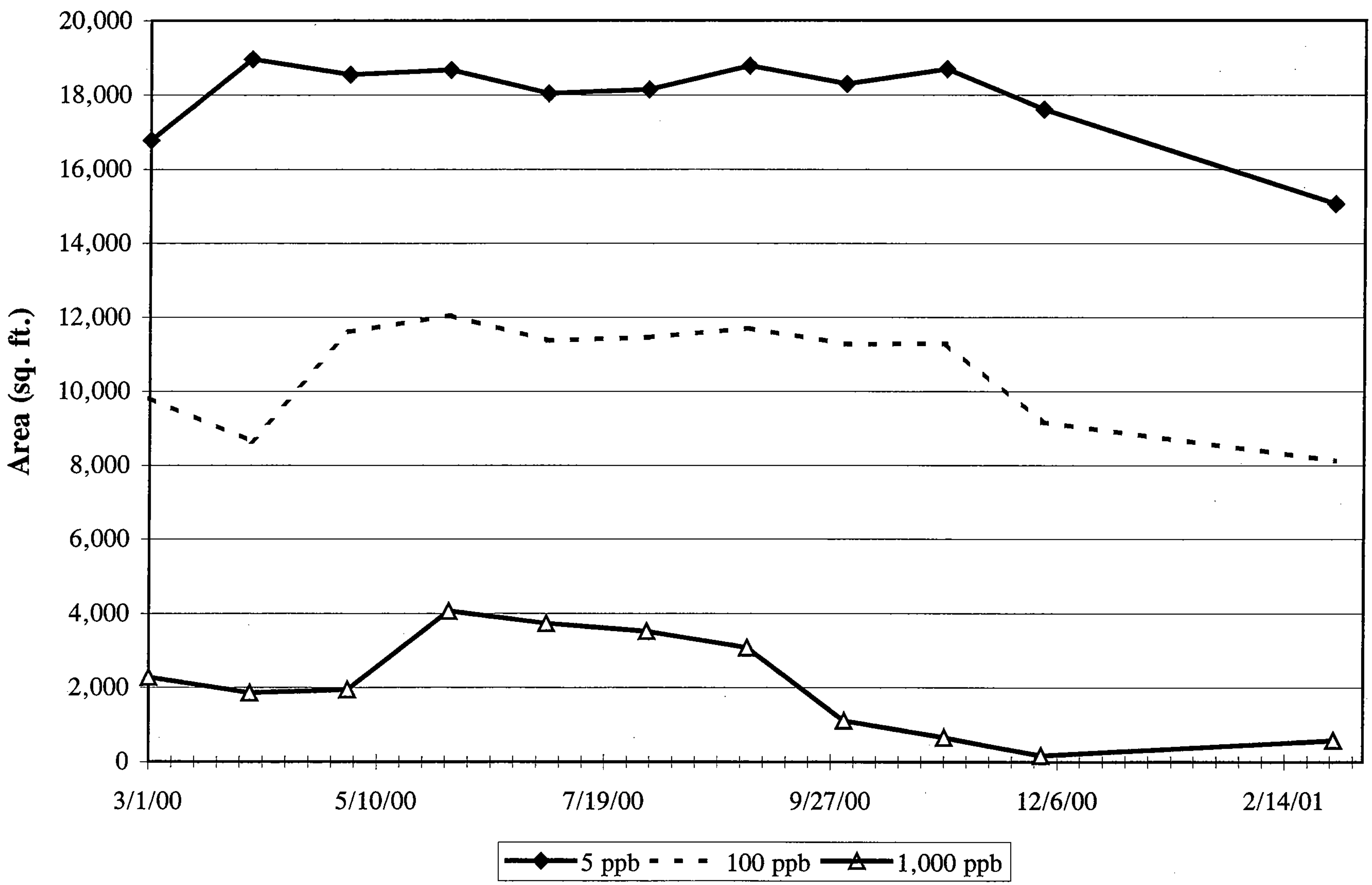
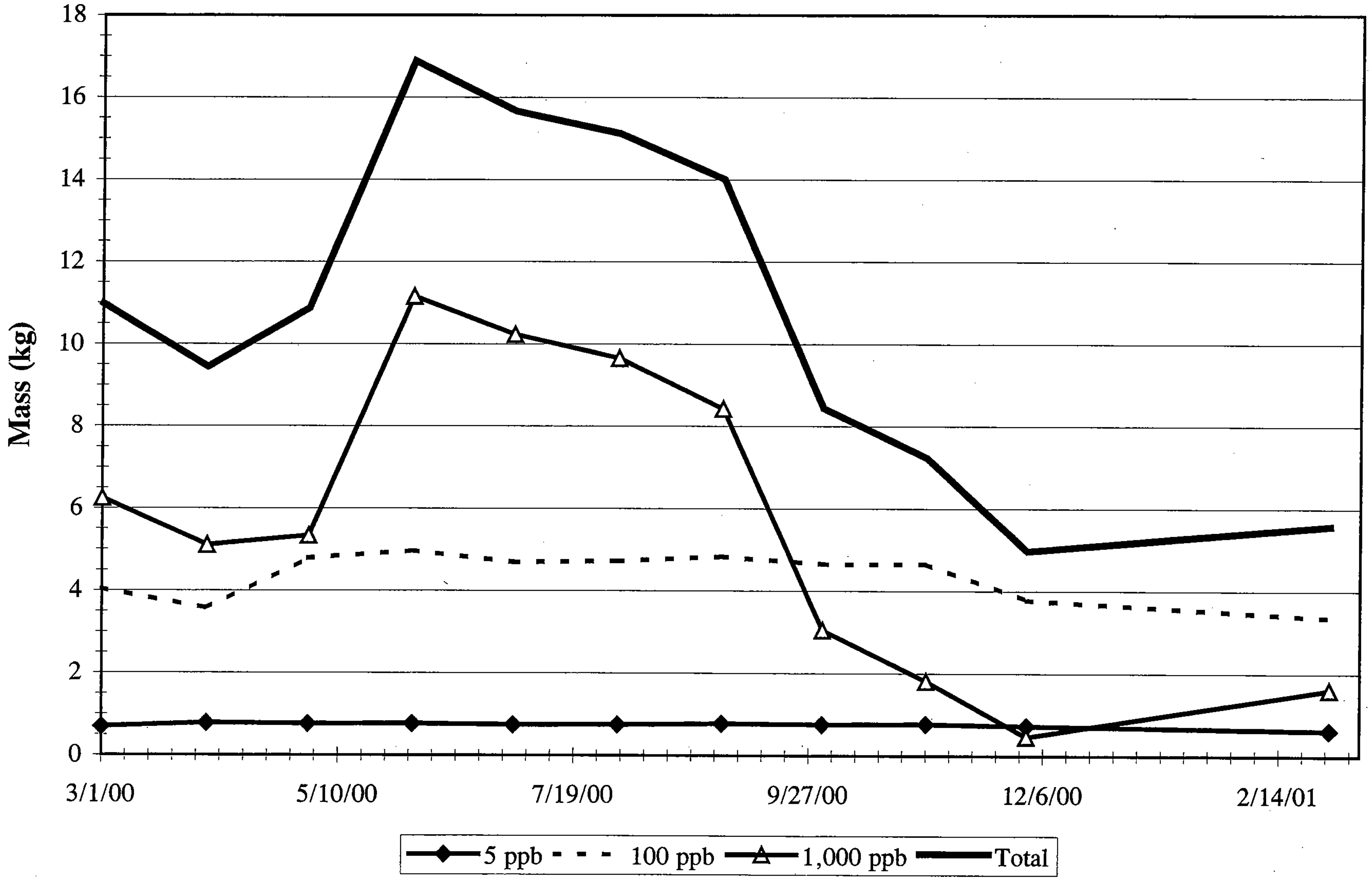


**Figure 7-2b**
**AOC A Pilot Study TCE Mass Trends**



*Discussion*

As expected, the most significant mass change was observed in the 1,000 $\mu$g/L plume. Relative to March 2000 (baseline sampling event), the TCE mass in this part of the plume decreased by approximately 75%. Coupled with the relatively minor decreases in the other portions of the pilot study area plume, total TCE mass decreased by 50% in one year (≈5 pounds). Comparatively, if measured from June 2000, when the 1,000 $\mu$g/L plume was largest, the overall TCE mass actually decreased by 2/3 or about 10 pounds in nine months.

As shown on Figure 7-2a and b, and as discussed in Section 7.1.1, concentration and plume area fluctuations occurred during the pilot study. Initial fluctuations are likely attributed to the (1) hydraulic effects from the startup of the recirculation system as TCE was drawn towards the pilot study area, (2) microorganism acclimation delay, and (3) subtle variations in the contouring effort, which was done manually. Concentration, mass, and area changes during the latter portion of the study are a result of reductive dechlorination. Because the high concentrations were targeted by the injection system, and the microbes invariably acclimate faster to areas with higher electron donor and acceptor concentrations, the 1,000 $\mu$g/L zone decreased first (August/September) followed by the 100 $\mu$g/L (November) and the 5 $\mu$g/L plume (November/ December).

## 7.2 Geochemistry Analysis

### 7.2.1 Field Data

When possible during the study, the field data were measured on a weekly or biweekly basis from the treatability monitoring wells and monthly from the extraction and reinjection wells. The results are summarized in Appendix D. The parameters include ammonia, $CO_2$, DO, ORP, and orthophosphate data. ORP data are also plotted on the VOC data graphs in Appendix B to demonstrate the relation between reducing conditions and reductive dechlorination of TCE and its daughter products.

**DO and ORP**

An overall observation of DO data indicates anaerobic conditions in the aquifer. Groundwater near the reinjection wells had very low DO concentrations from the middle of the study through system shutdown. Low ORP values were coincident with the low DO concentrations suggesting reducing conditions in the aquifer. Comparatively, DO concentrations were relatively elevated and ORP values were generally positive throughout the remainder of the study area until the system was shutdown. As soon as groundwater recirculation ceased, ORP values in the reinjection wells, both rows of downgradient monitoring wells, and 007G4LF became negative; some measurements were as low as -244 mV, which is sufficiently anaerobic for *cis*-1,2-DCE degradation.

**Carbon Dioxide**

$CO_2$ readings in Appendix D show that the critical monitoring wells 007G58LF, 007G59LF, 007G62LF, and 007G63LF did not show a discernible trend of any kind for this constituent. Moreover, $CO_2$ values in background well 007G3LF were in the same range as reported for the treatability areas wells. Therefore, for this treatability study, $CO_2$ readings may not be a valuable indicator of enhanced microbial activity.

### 7.2.2 Laboratory Data

Nutrient and geochemical data were collected monthly from the pilot study area wells and analyzed in the laboratory. Nutrient measurements include ammonia, phosphate, and TKN, while geochemical parameters of significance include TOC, nitrate, and chloride. These analyses were performed to check the adequacy of nitrogen and phosphorus as microbial nutrients in groundwater. The results are summarized in Appendix D.

**TOC:TKN:Phosphorus (C:N:P) Ratios**

Ratios of TOC to TKN to phosphorus are summarized in Table 7-7. For most events and all sampled wells, these ratios show that nitrogen and phosphorus (the two most essential nutrients for microbial activity) are unlikely to have limited microbial activity in the aquifer. Based on an average composition of cell tissue of $C_5H_7NO_2$, about 12.4% by weight of nitrogen will be required. The phosphorous value is assumed to be one-fifth of this value (this equates to a 100:20:4 C:N:P ratio). These are typical values, not fixed quantities, because it has been shown that the percentage distribution of nitrogen and phosphorus in cell tissue varies with the age of the cell and environmental conditions (Metcalf & Eddy, 1991). For measurable events (i.e., when TOC was detectable), the pilot-study nutrient ratios commonly met literature requirements. In fact, as shown in Appendix D, nitrogen and phosphorus were above detection limits in some of the samples in which TOC was not detected. As such, nitrogen and phosphorus were available at adequate levels to sustain microbial degradation in the aquifer.

**Iron**

Iron was measured in three wells during the March and April sampling events. Results presented in Section 7.2.2 show significant concentrations of iron in the fluvial deposits that could assist the microbially-mediated reduction of VC under the appropriate conditions. This may be a critical factor when a mainly aerobic environment such as the fluvial deposits is converted to one that is more anaerobic. Under these converted conditions, the aerobic degradation of VC could be impeded and this daughter product could accumulate unless significant amounts of iron could sustain degradation even under more reducing conditions.

**Hydrogen Measurements**

In May 2000, three wells were sampled for hydrogen and methane. Table 7-8 shows the results from this event. The low methane concentrations indicate that the aquifer was unlikely to be methanogenic. The hydrogen values, however, indicate conditions in the aquifer were favorable

**Table 7-7**
**C:N:P Ratios**

| Well | Baseline | A-A Operation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3/00 | 4/00 | 5/00 | 6/00 | 7/00 | 8/00 | 9/00 | 10/00 | 11/00 | 12/00 |
| 007G3LF | no carbon | no carbon | no carbon | no carbon | no carbon | no carbon | no carbon | NS | NS | 100:50:4 |
| 007G57LF | 100:19:1.7 | no carbon | 100:33:10 | no carbon | no carbon | no carbon | no carbon | 100:ND:2.3 | no carbon | 100:ND:ND |
| 007G60LF | 100:35::4.1 | no carbon | no carbon | no carbon | no carbon | no carbon | 100:26:3.5 | NS | NS | 100:1.4:1.6 |
| 007G61LF | 100:13:1.5 | 100:12:10 | no carbon | no carbon | no carbon | 100:18:4.2 | 100:2.4:0.9 | NS | NS | 100:1.2:ND |
| 007G62LFA | NS | NS | NS | NS | NS | 100:9.2:0.8 | 100:6.4:0.2 | 100:ND:0.5 | 100:ND:ND | 100:ND:0 |
| 007G62LFB | NS | NS | NS | NS | NS | 100:5.4:0.4 | 100:10:0.3 | 100:ND:0.5 | 100:ND:ND | 100:0.3:0 |
| 007G63LFA | NS | NS | NS | NS | NS | 100:4.4:0.3 | 100:13:0.5 | 100:ND:2.4 | 100:0.6:ND | 100:0.2:0 |
| 007G63LFB | NS | NS | NS | NS | NS | 100:4.5:0.8 | 100:11:0.9 | 100:ND:1.1 | 100:0.6:ND | 100:0.20 |
| 007G58LFA | no carbon | no carbon | no carbon | no carbon | no carbon | 100:ND:16 | no carbon | no carbon | 100:ND:ND | 100:ND:10 |
| 007G58LFB | no carbon | no carbon | no carbon | no carbon | no carbon | no carbon | no carbon | no carbon | 100:ND:ND | 100:ND:286 |
| 007G59LFA | 100:12:1.2 | 100:40:3 | 100:50:1.9 | no carbon | no carbon | 100:43:5.7 | no carbon | no carbon | 100:ND:ND | no carbon |
| 007G59LFB | 100:ND:2.7 | no carbon | no carbon | no carbon | no carbon | no carbon | no carbon | 100:ND:19 | 100:ND:ND | no carbon |
| 007G4LF | no carbon | no carbon | no carbon | no carbon | no carbon | no carbon | no carbon | no carbon | 100:ND:ND | 100:ND:2.3 |
| 007G4UF | no carbon | no carbon | no carbon | no carbon | no carbon | no carbon | no carbon | 100:ND:7.3 | 100:ND:ND | 100:ND:1.1 |
| 007G21LF | no carbon | no carbon | no carbon | no carbon | no carbon | 100:60:4.5 | no carbon | no carbon | NS:ND:ND | no carbon |

***Notes:***
ND = nondetect
no carbon = TOC was below detection limits; therefore, no ratio was calculated
NS = not sampled

**Table 7-8**
**Hydrogen and Methane Results (5/12/00)**

| Well | Hydrogen (nM/L) | Methane (μg/L) |
|---|---|---|
| 007G04LF | 1.96 | 0.042 |
| 007G04UF | 2.02 | 0.050 |
| 007G58LFA | 2.07 | 0.038 |
| 007G58LFB | 1.65 | 0.043 |

*Note:*
nM/L = nanomoles per liter

for sulfate-reduction and fairly conducive to reductive dechlorination of PCE and TCE. According to the *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water* (USEPA, 1998), hydrogen concentrations > 1 nM/L indicates the strong potential for reductive dechlorination. Further, if hydrogen concentrations are high enough to support sulfate reduction or methanogenesis, then reductive dechlorination is probably occurring, even if other geochemical indicators do not indicate that reductive dechlorination is possible (USEPA, 1998).

**Heterotrophic Plate Count (HPC)**

To monitor the microbial activity in the fluvial deposits aquifer, the wells were sampled monthly for HPC. The results for HPC are presented in Appendix D with the field and laboratory geochemical data. The mean values for all the wells ranged from $2.9 \times 10^3$ to $1.4 \times 10^6$ colony forming units (CFUs) per mL. There were no significant changes in any of the wells throughout the study. Most wells showed mean concentrations of $10^3$ to $10^4$ CFUs per mL. Aquifer augmentation did not appear to induce a significant increase in heterotrophic microbial populations. However, based on the *cis*-1,2-DCE production during the study, existing microorganisms appear to possess the capability of reducing TCE given the appropriate geochemical environments.

### 7.2.3 Post-Shutdown Geochemistry

Post-shutdown DO and ORP data indicate the continuation of reducing or anaerobic conditions three months after system shutdown. In particular, the aquifer in the vicinity of the two reinjection wells indicates the development of a reducing "stagnant" zone which is reflected in the sharp decrease in TCE and the buildup of VC. ORP readings in the direction of groundwater flow indicate less reducing conditions towards wells 007G62LF and 007G63LF and a gradual tendency towards the aerobic range at wells 007G58LF, 007G59LF, and 007G04LF, though groundwater still remains reducing in the entire treatability-study area. Over time, groundwater could become more aerobic and return to post-treatability conditions as the added carbon (acetate and fructose) is completely consumed.

## 7.3 Hydraulic Analysis

Based on groundwater elevations measured during the RFI, groundwater flows primarily to the northwest with localized small scale deviations. The hydraulic performance of the sequential A-A system was evaluated through (1) qualitative analysis of the potentiometric surface as measured during sequential sampling, and (2) analytical flow analysis of the potentiometric surface as measured during the sequential sampling.

### 7.3.1 Qualitative Analysis

Appendix E presents the water levels measured in each of the monitoring wells during the study, and Figures 1 through 8 in Appendix F present the modeled piezometric surface for each measurement event. The potentiometric contours are generated by statistical means only and do not take into account other factors (e.g., geology).

The measurement events included a baseline (3/7/00), a system start up (3/14/00), a series of regular monthly events (3/23/00 to 11/15/00), and a shutdown (12/12/00). Because the emphasis for this analysis is on the performance of the treatment system, only events that had water-level measurements for the extraction and re-injection wells were used in the analyses (baseline, start-up, and six sampling events covering a 180-day period of performance).

The baseline condition potentiometric surface exhibits a "tongued" high in the general area of monitoring wells 007G04LF and 007G04UF, with a longitudinal axis directed in a northwesterly azimuth (Figure 1, Appendix F). Northeast of this the gradient azimuth and magnitude is relatively constant towards the north-northwest. Following system startup, the potentiometric surfaces from 4/10/00 to 7/16/00 also exhibit a similar extension downgradient, but the axis deviates somewhat in direction and magnitude. This may be associated with the injection of groundwater, which could create a downgradient extension of higher elevation isopleths. The direction and magnitude would vary depending on the injection rate and the extraction rate from well 007G57LF. The potentiometric surface for 8/21/00 exhibits a retraction of lower elevation ispoleths towards the extraction well, with an axis azimuth towards the southwest. This is related to a relative rise in the head in injection well 007G60LF, which was the results of screen clogging from fine-grained sediment and high levels of iron hydroxides.

After this date, a filter system was installed to help prevent recurrence of this relative rise in water level. The 9/19/00 potentiometric surface, which is the final surface profiled during the 180-day period of performance, exhibits a high near the extraction well, and a subdued "tonguing" of the higher area towards the northwest, which is what would be expected during a static operation of the extraction/injection hydraulics. Unfortunately, the surface also exhibits a relative low to the southeast of well 007G60LF; this is a statistical extrapolation of the lower elevation of this well versus that of 007G61LF, 007G62LF and 007G63LF, and should not be considered as "real." The only alternative to eliminate this feature for the particle tracking (see Section 7.3.2) is to insert "dummy points," an exercise which was not conducted in the interest of presenting only valid data. In summary, conclusions that may be inferred from this evaluation include:

- Although some local rise in the potentiometric surface was noted in the vicinity of the monitoring wells between the injection and extraction wells as a baseline condition, the observed rise may be the result of drilling artifacts.

- Operation of the system appears to have been quite variable over the performance period, resulting in a number of perturbations of the basic potentiometric configuration. However, by 9/19/00, hydraulic conditions appear to be consistent with the intended design for injection and extraction.

### 7.3.2 Quantitative Analysis

To assess the hydraulic performance of the system, particle tracking modeling was conducted for the period of operation. This entailed entering the grid file for each potentiometric surface, along with appropriate aquifer parameter information, into GWPath (Schafer, 1992), a commercially available software platform for forward and reverse pathline analysis. The reader is referred to the treatability study work plan for specifics on GWPath. Table 7-9 provides the input parameters used for the analyses. For each of the sequential sampling events from April through September, reverse tracking was conducted for the extraction well, and forward tracking was conducted for each of the re-injection wells. Figures 9 through 14 in Appendix F present the results of these exercises. Similar to the qualitative evaluation, only events that included extraction and re-injection well measurements (post system start-up) were included for analysis.

Pathlines illustrating zones of influence for the period of the first 60 days exhibit very little movement of groundwater towards the hydraulic sources and sinks. The period of the next 60 days exhibits a fairly consistent movement of water away from the injection wells, but

**Table 7-9**
**GWPath Input Parameters**

| Parameter | Value | Source/Logic |
|---|---|---|
| Flow domain | Horizontal | Lateral pathline analysis. |
| Model domain grid | $X_{min}$ = 813673; $X_{max}$ = 813897<br>$Y_{min}$ = 391936; $Y_{max}$ = 392560<br>$X_{spacing}$ = 6.4; $Y_{spacing}$ = 13<br>Rows = 36; Columns = 49 | Incorporation of all wells monitored. |
| Hydraulic conductivity | X = 5 ft/d; Y = 5 ft/d | Design memo; Assumed lateral isotropy. |
| Porosity | 25% | Value used by USGS in transport modeling; from core sample. |
| Hydraulic head file | Grid file for each sampling event pot surface | Based on model domain grid specs. |
| Travel time | Determined for each sampling event; 3/14/00 as start time. | Period of operation from start-up. |
| Output | Extraction well — reverse tracking; Re-injection well — forward tracking | Lateral tracking of pathlines. |

very little movement towards the extraction well. This is a function of the relatively low gradient mapped in the vicinity of well 007G57LF. The pathline analysis for the 8-21-00 period, which had a considerably different potentiometric configuration, demonstrates the effect of the steeper hydraulic gradient from the injection wells towards the northeast. Finally, the pathline analysis for the period 9-19-00 shows the response of pathlines towards the hydraulic sink of well 007G60LF.

Theoretically, the forward pathlines from the injection wells would extend to the northwest towards the extraction well. Similar to the other periods, however, the extraction well influence appears to be very small, which likely is a result of the flat gradient in the vicinity of 007G57LF.

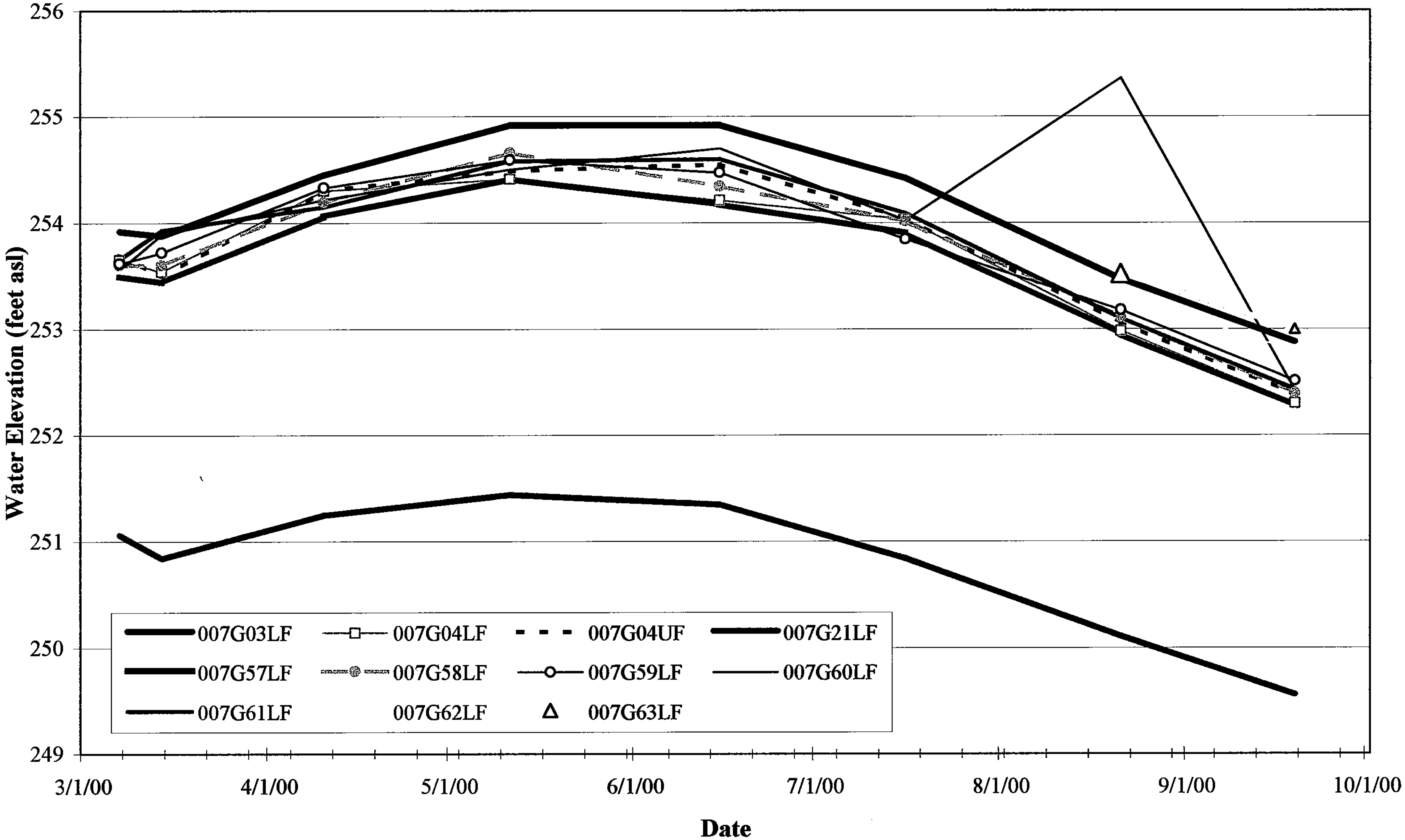
Pathline azimuths are not identical for each evaluation period as they are influenced by the selected potentiometric surface. The azimuths reflect the gradient direction, which was noted to change, likely as a function of the variable injection rates. Therefore, the system, through the period of performance, operated as a highly transient system. The optimal static conditions (that is, relative highs near the injection wells, with a capture influence associated with the lower downgradient extraction well) may require more than the 180 days of operation to establish.

In summary, the hydraulic performance analytical evaluation indicates that injected water did not migrate into the capture zone of the extraction well during the limited time period of the pilot study, nor did the migration of injected water stay consistent in terms of direction. Extracted water, based on pathline analysis only, is derived from the immediate vicinity of the extraction well, which is thought to be a function of the relatively flat gradient.

**Water-Level Trends**

Over the course of the study, water levels generally exhibited an increase through May, and then a general decrease until December. To evaluate the uniformity or non-uniformity of these trends, water-level trends for each well were plotted, and are presented as Figure 7-3. As demonstrated by the graph, all wells demonstrate similar trends, and thus were somewhat equally affected, with the exception of an increase in head in well 007G60LF during August. This exception may be a reflection of an increase in injection rate in that particular well in July.

## Figure 7-3
## A-A System Water Levels



# 8.0 CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

The main objective of performing the A-A treatability study in the fluvial deposits aquifer at the selected location within AOC A was to determine the feasibility and effectiveness of using enhanced in situ bioremediation to treat PCE- and TCE-contaminated groundwater. Historically, the fluvial deposits aquifer in the treatability area has been slightly aerobic and has very low concentrations of natural carbon. Therefore, nutrients (fructose/acetate and ammonium phosphate) were added during the study to stimulate indigenous microorganisms to change the redox state of the aquifer.

After the nine-month treatability study, it appeared that reductive dechlorination of PCE and TCE is feasible via bioaugmentation. The attainment of reducing conditions was confirmed by negative ORP measurements, low DO concentrations, and elevated hydrogen concentrations during field geochemical sampling. However, the most significant observation was the two-order-magnitude increase in *cis*-1,2-DCE concentrations in the study area monitoring wells.

Pilot study results also indicated that *cis*-1,2-DCE did not degrade at a rate commensurate to its formation during system operation. It accumulated because of persistent anaerobic conditions where natural aerobic conditions were expected to stimulate its degradation. *Cis*-1,2-DCE concentrations increased over time and were measured farther downgradient as the study progressed. As such, sparging would likely be required in a full-scale system to accelerate its removal.

Preliminary TCE mass balances and parent-compound degradation rates were also performed during the evaluation. Preliminary estimates indicate a 50% reduction in TCE mass in the area. Zero-order rates for PCE ranged from 0.219 $day^{-1}$ (80 $yr^{-1}$) to 0.226 $day^{-1}$ (83 $yr^{-1}$) while first-order rates ranged from 0.009 $day^{-1}$ (3.3 $yr^{-1}$) to 0.010 $day^{-1}$ (3.7 $yr^{-1}$). Comparatively, zero-order rates for TCE ranged from 8.05 $day^{-1}$ (2,940 $yr^{-1}$) to 8.29 $day^{-1}$ (3,025 $yr^{-1}$) and first-order rates ranged from 0.016 $day^{-1}$ (5.8 $yr^{-1}$) to 0.026 $day^{-1}$ (9.5 $yr^{-1}$). These numbers were compared to literature values for natural attenuation sites. The comparison shows rates of removal of TCE equal to or greater than reported values.

Although the system operation appeared to be variable over the study period, hydraulic conditions appeared to be consistent with the extraction and injection system design by about six months after start up. The analytical evaluation of the hydraulic performance indicates that injected water has not yet migrated to the capture zone of the extraction well during the limited period of operation of the pilot study, nor has the migration of injected water been consistent in terms of direction. The extracted water was shown to have originated from the immediate vicinity of the extraction well, which is a function of the relatively flat hydraulic gradient.

Chemical and geochemical data from the treatability-study wells collected three months after system shutdown indicate that the system was gradually returning to pre-treatability conditions. VC was detected at the reinjection wells for the first time as a result of the creation of a "stagnant" reducing zone in the vicinity of the wells. VC, as well as *cis*-DCE are expected to gradually decrease over time along the groundwater flow path. Overall, the groundwater in the vicinity of the injection wells remains anaerobic but is likely to gradually turn aerobic after all the remaining augmented carbon is consumed.

**Recommendations**

The A-A treatability study was the first attempt to provide an engineered solution to remedying the highest concentrations of chlorinated solvent contamination in the aquifer fluvial deposits at AOC A. The results show that this technology can feasiblely reduce TCE at AOC A. Preliminary calculations of degradation rates and mass reductions should be used during the CMS and reported as a baseline against which other treatment alternatives can be compared.

Preliminary calculations of degradation rates and mass reductions should be used during the CMS and reported as a baseline against which other treatment alternatives can be compared.

The location, spacing, and number of extraction, reinjection, and pumping wells for the treatibility study were based on site investigation data and hydrogeological modeling. This information can be used to design a treatment system at other locations at AOC A where treatment is required.

This study used two carbon sources, fructose and sodium acetate. Fructose or molasses is the preferred carbon source because cost of carbon amendment would be a significant factor in deciding the type of bioaugmentation for treatment of larger areas or areas with higher TCE concentrations.

This study showed that *cis*-1,2-DCE degradation does not occur to any measurable extent in the amended anaerobic zone of the study area. Historically, *cis*-1,2-DCE concentrations in the aquifer have been less than 50 $\mu$g/L. Therefore, the exact degradation mechanisms for this compound in this aquifer have not been specifically examined. Continued periodic sampling of wells in the treatability-study area and in downgradient wells is recommended to understand the fate of this daughter product. Enhancing the aquifer to create strongly aerobic conditions via sparging may degrade this daughter product faster in areas where it is now present. This is a possible alternative for complete treatment of chlorinated compounds at AOC A.

Groundwater samples will be collected from the treatibility study wells and analyzed for VOC concentrations in July/August 2001, six months after system shutdown, to evaluate further trends in TCE and daughter product concentrations. Geochemical parameters will continue to be examined on a biweekly basis for two years to evaluate the pattern of change from anaerobic to aerobic conditions.

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# APPENDIX A

# WELL CONSTRUCTION LOGS

ENSAFE

# BORING LOG of 007G57LF



NSA MID-SOUTH
Millington, TN.

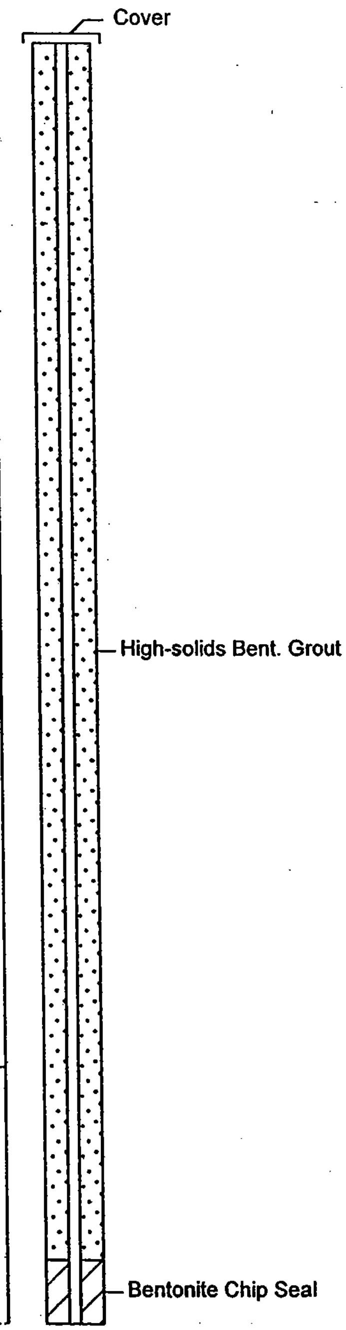
Location: Building N-126

Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 0850 12/1/99 | Northing | : 392231.80 |
| Finished | : 0630 12/1/99 | Easting | : 813751.34 |
| Drilling Method | : Rotasonic | TOC Elevation | : 283.17 |
| Drilling Company | : Boart-Longyear | Total Depth | : 75 feet |
| Geologist | : Bart Douglas | Well Screen | : 42 to 72 feet |

| Depth in Feet | Surf. Elev. 283.17 | SAMPLES | % Recovery | FID (ppm) | GRAPHIC LOG | SOIL CLASS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| 0 | | | | | | | CONCRETE |
| | | | | | | ML | CLAYEY SILT |
| | | 1 | 100 | 0 | | | (0.5-6) Dark-brown, moist, and stiff. |
| 5 | | | | | | | |
| 10 | | 2 | 100 | 0 | | | (6-15) Brown, medium to stiff, and wet. |
| 15 | | | | | | | |
| 20 | | 3 | 100 | 0 | | | (15-26) Dark-gray and medium. |
| 25 | | | | | | | (26-29) Gray and soft. |
| 30 | | 4 | 100 | 0 | | | (29-32) Mottled brown and gray with a trace of fine sand throughout. |
| | | | | | | SC | CLAYEY SAND |
| | | | | | | | (32-34) Mottled brown to gray and fine-grained. |
| 35 | | 5 | 100 | 0 | | | (34-42) Reddish-brown to orange and fine- to medium-grained with some clay. |
| 40 | | 6 | 100 | 0.9 | | | |

Well: 007G57LF
Elev.: 283.17

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ENSAFE

# BORING LOG of 007G57LF



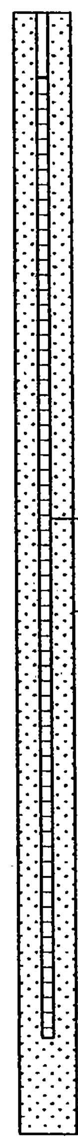
NSA MID-SOUTH
Millington, TN.

Location: Building N-126
Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 0850 12/1/99 | Northing | : 392231.80 |
| Finished | : 0630 12/1/99 | Easting | : 813751.34 |
| Drilling Method | : Rotasonic | TOC Elevation | : 283.17 |
| Drilling Company | : Boart-Longyear | Total Depth | : 75 feet |
| Geologist | : Bart Douglas | Well Screen | : 42 to 72 feet |

| Depth in Feet | Surf. Elev. 283.17 | SAMPLES | % Recovery | FID (ppm) | GRAPHIC LOG | SOIL CLASS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| 40 | | 6 | 100 | 0.9 | | SC | |
| | | 7 | 100 | 1.4 | | SP | SAND, reddish-brown to tan and fine-grained. |
| 45 | | 8 | 100 | 1.1 | | GW | SANDY GRAVEL, well graded, reddish-brown with medium sand. |
| 50 | | 9 | 100 | 0.65 | | GW | |
| | | 10 | 100 | 1 | | GW | |
| 55 | | 11 | 100 | 1.3 | | SW | GRAVELLY SAND,well graded, tan, and medium- to coarse-grained with gravel content varying throughout. |
| 60 | | 12 | 100 | 0.96 | | SW | |
| | | 13 | 100 | 1.2 | | SW | |
| 65 | | 14 | 100 | 2.5 | | SW | |
| | | 15 | 100 | 1.1 | | SW | |
| 70 | | 16 | 100 | 0 | | GW | SANDY GRAVEL, well graded with coarse sand. |
| | | 17 | 100 | 0 | | ML | CLAYEY SILT, dark-brown to gray with mica and lignite specks throughout. Cockfield contact at 72 feet. |
| 75 | | | | | | | |
| 80 | | | | | | | |

Well: 007G57LF
Elev.: 283.17

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# ENSAFE

# BORING LOG of 007G58LF



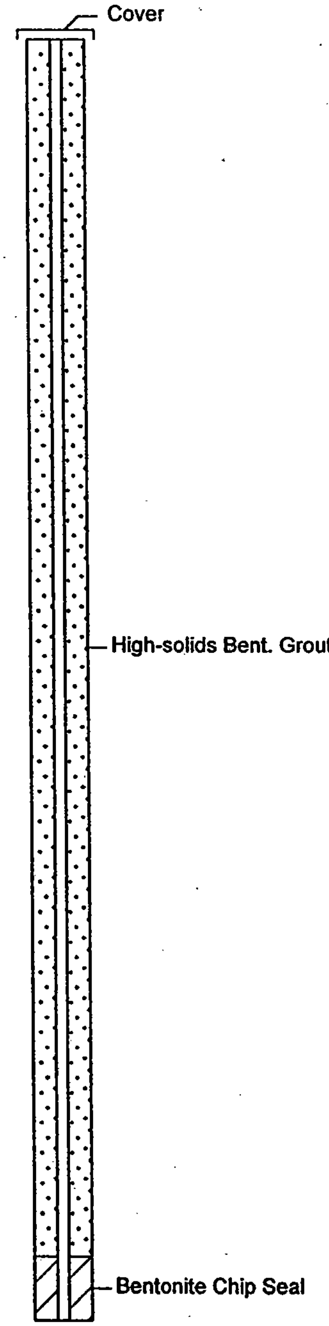
NSA MID-SOUTH
Millington, TN.

Location: Building N-126
Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 0930 11/22/99 | Northing | : 392157.47 |
| Finished | : 0910 11/23/99 | Easting | : 8137755.32 |
| Drilling Method | : Rotasonic | TOC Elevation | : 283.22 |
| Drilling Company | : Boart-Longyear | Total Depth | : 80 feet |
| Geologist | : Bart Douglas | Well Screen | : 42 to 72 feet |

| Depth in Feet | Surf. Elev. 283.22 | SAMPLES | % Recovery | FID (ppm) | GRAPHIC LOG | SOIL CLASS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| 0 | | | | | | | CONCRETE |
| | | | | | | GP | GRAVEL and SAND FILL |
| | | 1 | 100 | 0 | | | CLAYEY SILT<br>(2-5) Dark-brown, dry, and stiff. |
| 5 | | | | | | | |
| | | | | | | | Wet at 7'. |
| 10 | | 2 | 100 | 0 | | | (5-15) Brown, and medium to soft. |
| | | | | | | ML | |
| 15 | | | | | | | |
| 20 | | 3 | 100 | 0 | | | (15-25) Reddish-brown w/ trace fine sand, moist, and medium to stiff. |
| 25 | | 4 | 100 | 0 | | CL | SANDY CLAY, reddish-brown, moist and stiff with fine sand. |
| | | 5 | 100 | 2 | | | CLAYEY SAND |
| 30 | | | | | | | (29-35) Reddish-brown and fine-grained with silt. |
| | | 6 | 100 | 1.6 | | | |
| | | 7 | 100 | 2 | | SC | |
| 35 | | | | | | | |
| | | 8 | 100 | 16.7 | | | (35-39) Changing to tan and yellowish-brown. |
| | | 9 | 100 | 27 | | | |
| 40 | | | | | | SM | |

Well: 007G58LF
Elev.: 283.22

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**ENSAFE**

# BORING LOG of 007G58LF



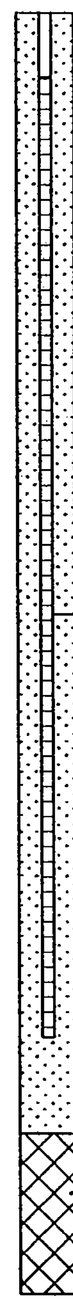
NSA MID-SOUTH
Millington, TN.

Location: Building N-126
Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 0930 11/22/99 | Northing | : 392157.47 |
| Finished | : 0910 11/23/99 | Easting | : 8137755.32 |
| Drilling Method | : Rotasonic | TOC Elevation | : 283.22 |
| Drilling Company | : Boart-Longyear | Total Depth | : 80 feet |
| Geologist | : Bart Douglas | Well Screen | : 42 to 72 feet |

| Depth in Feet | Surf. Elev. 283.22 | SAMPLES | % Recovery | FID (ppm) | SOIL CLASS | DESCRIPTION |
|---|---|---|---|---|---|---|
| 40 | | 9 | 100 | 27 | SM | SILTY SAND, light-brown to tan and fine- to medium-grained with a trace of clay. |
| | | 10 | 100 | 102 | SM | |
| 45 | | 11 | 100 | 104 | SW | GRAVELLY SAND,well graded. (45-49) Tan to gray and fine- to medium-grained with a trace of gravel. |
| 50 | | 12 | 100 | 100 | SW | (49-55) Tan and medium-grained with gravel throughout. |
| | | 13 | 100 | 136 | SW | |
| 55 | | 14 | 100 | 36 | SW | |
| | | 15 | 100 | 47 | SW | (55-65) Light-brown to tan, medium- to coarse-grained and gravelly |
| 60 | | 16 | 100 | 103 | SW | |
| | | 17 | 100 | 213 | SW | |
| 65 | | 18 | 100 | 13 | GW | SANDY GRAVEL, well graded and brown with coarse sand. |
| | | 19 | 100 | 39 | GW | |
| 70 | | 20 | 100 | 35 | GW | |
| | | 21 | 0 | NA | ML | SANDY SILT, dark-reddish-brown to gray. |
| 75 | | 22 | 0 | NA | ML | Although there was no recovery from 72 to 80 feet, samples of sandy silt were smudged on the bottom 8 feet of the sampling rod. Therefore, the Cockfield contact was estimated at 72 feet. Native formation materials collapsed and backfilled the bottom 5 feet of the borehole. |
| 80 | | | | | | |

Well: 007G58LF
Elev.: 283.22



ENSAFE

# BORING LOG of 007G59LF



NSA MID-SOUTH
Millington, TN.

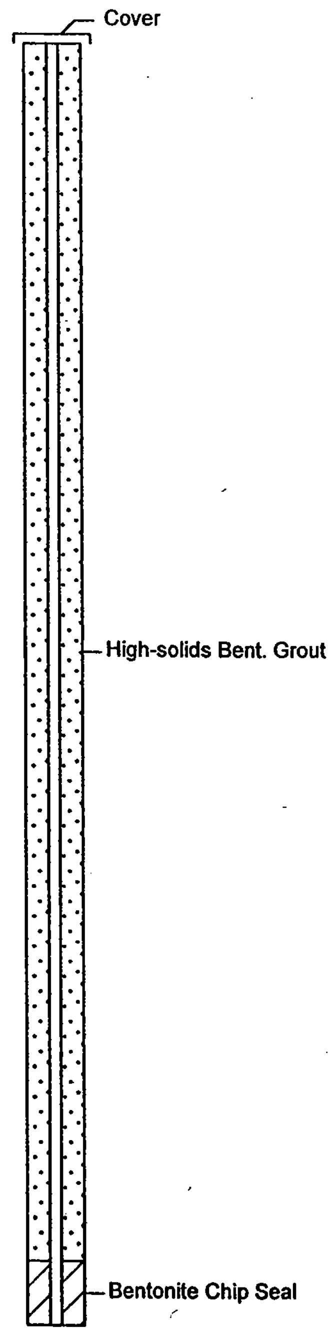
Location: Building N-126

Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 0930 11/23/99 | Northing | : 392163.98 |
| Finished | : 1500 11/29/99 | Easting | : 813790.26 |
| Drilling Method | : Rotasonic | TOC Elevation | : 283.17 |
| Drilling Company | : Boart-Longyear | Total Depth | : 75 feet |
| Geologist | : Bart Douglas | Well Screen | : 42 to 72 feet |

| Depth in Feet | Surf. Elev. 283.17 | SAMPLES | % Recovery | FID (ppm) | SOIL CLASS | DESCRIPTION |
|---|---|---|---|---|---|---|
| 0 | | | | | | CONCRETE |
| | | | | | GP | GRAVEL and SAND FILL |
| | | 1 | 100 | 2.3 | ML | CLAYEY SILT<br>(2-5) Dark-brown, dry, and very stiff. |
| 5 | | | | | | |
| 10 | | 2 | 35 | 0 | | (5-22) Medium to stiff. |
| 15 | | 3 | 100 | 2.2 | | |
| 20 | | 4 | 100 | 0 | | |
| | | 5 | 100 | 0.7 | | (22-25) Reddish-brown to orange-brown, moist, and medium. |
| 25 | | 6 | 100 | 4.4 | CL | SANDY CLAY, reddish-brown and stiff with fine sand and silt. |
| | | | | | SC | CLAYEY SAND, reddish-brown. |
| 30 | | 7 | 100 | 4.9 | | (28-32) Fine- to medium- grained. |
| | | 8 | 100 | 6.1 | | (32-35) Medium-grained. |
| 35 | | 9 | 0 | NA | | |
| | | 10 | 100 | 34 | | (35-40) Fine-grained. |
| 40 | | | | | | |

Well: 007G59LF
Elev.: 283.17



ENSAFE

# BORING LOG of 007G59LF



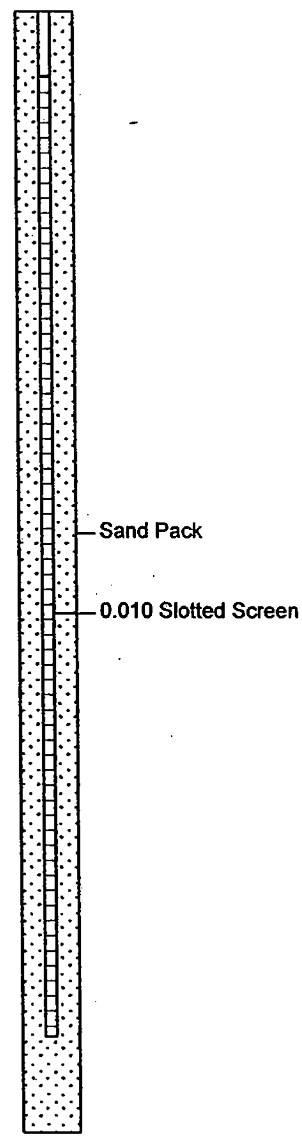
NSA MID-SOUTH
Millington, TN.

Location: Building N-126
Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 0930 11/23/99 | Northing | : 392163.98 |
| Finished | : 1500 11/29/99 | Easting | : 813790.26 |
| Drilling Method | : Rotasonic | TOC Elevation | : 283.17 |
| Drilling Company | : Boart-Longyear | Total Depth | : 75 feet |
| Geologist | : Bart Douglas | Well Screen | : 42 to 72 feet |

| Depth in Feet | Surf. Elev. 283.17 | SAMPLES | % Recovery | FID (ppm) | GRAPHIC LOG | SOIL CLASS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| 40 | | 10 | 100 | 34 | | SC | (40-42) Reddish-brown to tan. |
| | | 11 | 100 | 44 | | SP | SAND, light-brown to tan and fine-grained. |
| 45 | | 12 | 100 | 50 | | SW | GRAVELLY SAND, well graded, light-brown to tan and medium-grained. |
| 50 | | 13 | 100 | 69 | | GW | SANDY GRAVEL, well graded with medium- to coarse-grained sand. |
| | | 14 | 100 | 130 | | | |
| 55 | | 15 | 100 | 55 | | | |
| | | 16 | 100 | 19 | | | |
| | | 17 | 100 | 42 | | SW | GRAVELLY SAND, well graded and medium-grained. |
| 60 | | | | | | | |
| | | 18 | 100 | 117 | | | |
| 65 | | 19 | 100 | 33 | | GW | SANDY GRAVEL, well graded with medium sand. |
| 70 | | 20 | 100 | 38 | | | |
| | | 21 | 100 | 3.4 | | ML | CLAYEY SILT, dark-gray to brown, micacius and soft with lignite throughout. Cockfield contact at 72 feet. |
| 75 | | | | | | | |
| 80 | | | | | | | |

Well: 007G59LF
Elev.: 283.17




N:\WELL LOGS\ NSAMIDSOUTH\007G59LF.BOR

02

ENSAFE

# BORING LOG of 007G60LF



NSA MID-SOUTH
Millington, TN.

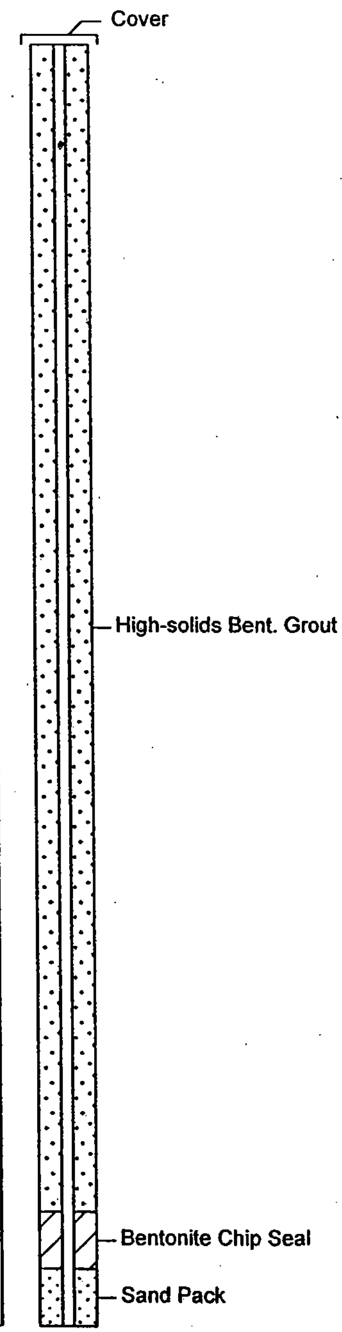
Location: Building N-126

Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 0730 11/30/99 | Northing | : 392114.00 |
| Finished | : 2200 11/30/99 | Easting | : 813797.36 |
| Drilling Method | : Rotasonic | TOC Elevation | : 283.26 |
| Drilling Company | : Boart-Longyear | Total Depth | : 85 feet |
| Geologist | : Bart Douglas | Well Screen | : 45 to 75 feet |

| Depth in Feet | Surf. Elev. 283.26 | SAMPLES | % Recovery | FID (ppm) | SOIL CLASS | DESCRIPTION |
|---|---|---|---|---|---|---|
| 0 | | | | | | CONCRETE |
| | | 1 | 40 | 0 | ML | CLAYEY SILT<br>(1-6.5) Dark-brown, moist, and medium. |
| 5 | | 2 | 100 | 3.2 | ML | |
| 10 | | 3 | 100 | 0.8 | ML | (6.5-19) Brown, soft and wet. Medium stiffness below 16 feet. |
| | | 4 | 100 | 3.4 | ML | |
| 15 | | 5 | 100 | 2.2 | ML | |
| | | 6 | 100 | 6.8 | ML | |
| 20 | | | | | ML | (19-23) Reddish-brown and medium. |
| | | 7 | 100 | 5 | ML | (23-25) With fine sand throughout. |
| 25 | | 8 | 100 | 9.9 | CL | SANDY CLAY, reddish-brown to orange-brown and medium with fine sand. |
| | | 9 | 100 | 3.7 | SC | CLAYEY SAND |
| 30 | | 10 | 100 | 9.3 | SC | (28-39) Reddish-brown to orange-brown, fine- to medium-grained, and stiff. |
| 35 | | 11 | 100 | 12 | SC | |
| 40 | | 12 | 100 | 24 | SC | (39-42) Orange-brown to tan and fine- to medium-grained with some clay. |
| | | 13 | 100 | 38 | SP | SAND, light-brown to tan and fine- to medium-grained. |
| 45 | | | | | | |

Well: 007G60LF
Elev.: 283.26

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02-2?-2000

ENSAFE

# BORING LOG of 007G60LF



NSA MID-SOUTH
Millington, TN.

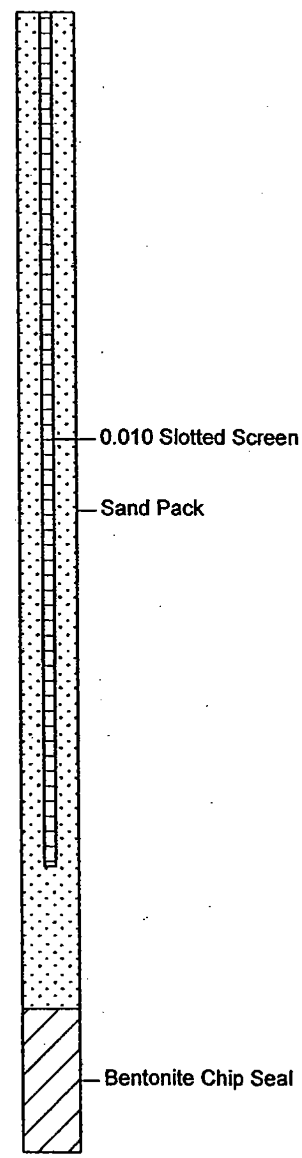
Location: Building N-126

Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 0730 11/30/99 | Northing | : 392114.00 |
| Finished | : 2200 11/30/99 | Easting | : 813797.36 |
| Drilling Method | : Rotasonic | TOC Elevation | : 283.26 |
| Drilling Company | : Boart-Longyear | Total Depth | : 85 feet |
| Geologist | : Bart Douglas | Well Screen | : 45 to 75 feet |

| Depth in Feet | Surf. Elev. 283.26 | SAMPLES | % Recovery | FID (ppm) | SOIL CLASS | DESCRIPTION |
|---|---|---|---|---|---|---|
| 45 | | | | | SP | |
| | | 14 | 100 | 25 | SW | GRAVELLY SAND, well graded. (46-50) Tan and medium-grained with a trace of gravel. |
| 50 | | 15 | 100 | 57 | | |
| | | 16 | 100 | 71 | | (50-65) Tan and medium- to coarse-grained with gravel content varying throughout. |
| 55 | | 17 | 100 | 37 | | |
| 60 | | 18 | 100 | 43 | | |
| | | 19 | 100 | 55 | | |
| 65 | | 20 | 100 | NA | | |
| | | 21 | 100 | NA | | (65-69) Brown to tan. |
| 70 | | 22 | 100 | NA | GW | SANDY GRAVEL, well graded with coarse sand. |
| | | 23 | 100 | NA | | |
| 75 | | | | | ML | SANDY SILT, gray and clayey with fine sand, mica, and lignite specks throughout. One reddish-orange iron concreation at 74.5. Cockfield contact at 74.5 feet. |
| 80 | | 24 | 0 | NA | | |
| 85 | | | | | | |
| 90 | | | | | | |

Well: 007G60LF
Elev.: 283.26

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02-28-2000

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# BORING LOG of 007G61LF



NSA MID-SOUTH
Millington, TN.

Location: Building N-126
Project #: CTO 0094

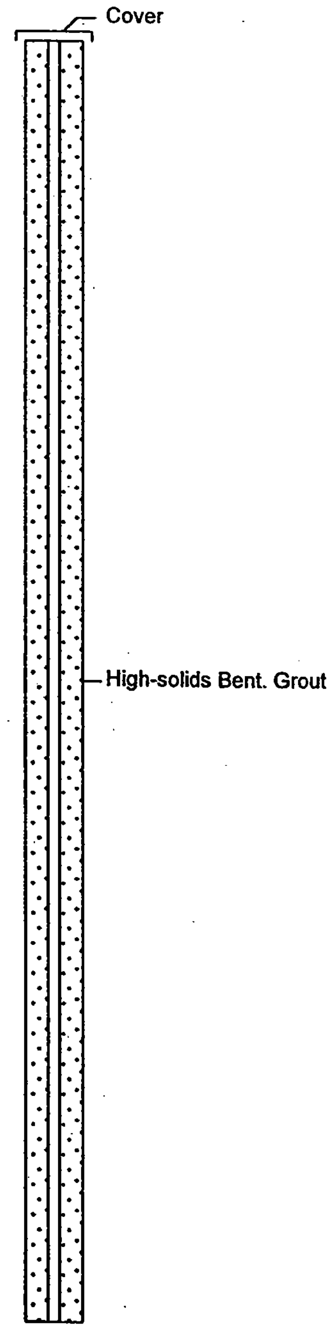
| | | | |
|---|---|---|---|
| Started | : 1000 12/2/99 | Northing | : 392122.48 |
| Finished | : 1800 12/2/99 | Easting | : 813813.14 |
| Drilling Method | : Rotasonic | TOC Elevation | : 283.04 |
| Drilling Company | : Boart-Longyear | Total Depth | : 75 feet |
| Geologist | : Bart Douglas | Well Screen | : 45 to 75 feet |

Surf. Elev. 283.04

| Depth in Feet | SAMPLES | % Recovery | FID (ppm) |
|---|---|---|---|
| 0–5 | 1 | 100 | 0 |
| 5–15 | 2 | 100 | 0 |
| 15–25 | 3 | 100 | 0 |
| 25–35 | 4 | 100 | 0 |
| 35–36 | 5 | 100 | 0 |
| 36–40 | 6 | 100 | 5.6 |

| Depth in Feet | SOIL CLASS | DESCRIPTION |
|---|---|---|
| 0–1 | | CONCRETE |
| 1–25 | ML | CLAYEY SILT<br>(1-4) Dark-brown.<br>(4-16) Brown.<br>(16-25) Reddish-brown. |
| 25–32 | CL | SANDY CLAY, reddish-brown to orange-brown with fine sand. |
| 32–38 | SC | CLAYEY SAND, reddish-brown to orange-brown and fine-grained. |
| 38–40 | SP | SAND, yellowish-brown to tan and fine- to medium-grained. |

Well: 007G61LF
Elev.: 283.04

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02-28-2000

**ENSAFE**

# BORING LOG of 007G61LF



NSA MID-SOUTH
Millington, TN.

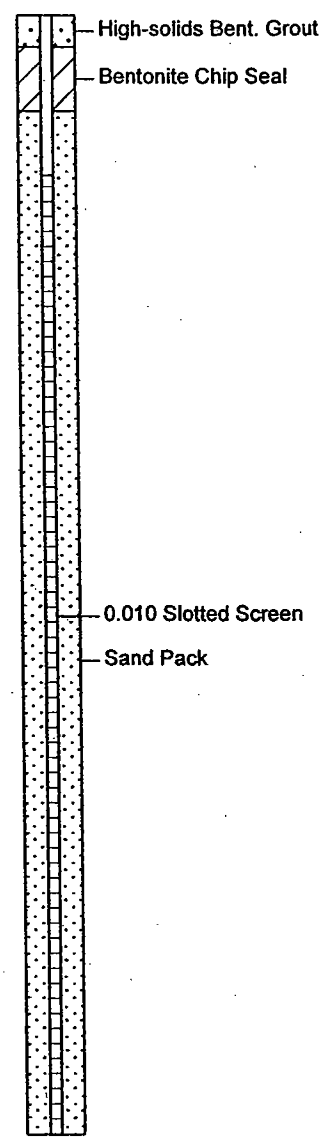
Location: Building N-126

Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 1000 12/2/99 | Northing | : 392122.48 |
| Finished | : 1800 12/2/99 | Easting | : 813813.14 |
| Drilling Method | : Rotasonic | TOC Elevation | : 283.04 |
| Drilling Company | : Boart-Longyear | Total Depth | : 75 feet |
| Geologist | : Bart Douglas | Well Screen | : 45 to 75 feet |

| Depth in Feet | Surf. Elev. 283.04 | SAMPLES | % Recovery | FID (ppm) | SOIL CLASS | DESCRIPTION |
|---|---|---|---|---|---|---|
| 40 | | 6 | 100 | 5.6 | SP | |
| | | 7 | 100 | 182 | SP | |
| 45 | | 8 | 100 | 57 | SP | |
| | | 9 | 100 | 13 | SW | GRAVELLY SAND, well graded and medium-grained. |
| 50 | | 10 | 100 | 93 | SW | |
| | | 11 | 100 | 285 | GW | SANDY GRAVEL, well graded with medium to coarse sand. |
| 55 | | 12 | 100 | 85 | GW | |
| | | 13 | 100 | 78 | GW | |
| 60 | | 14 | 100 | 37 | GW | |
| | | 15 | 100 | 78 | GW | |
| 65 | | 16 | 100 | 27 | GW | |
| 70 | | 17 | 100 | 18 | GW | |
| 75 | | | | | ML | CLAYEY SILT, gray with mica throughout. Cockfield contact at 74 feet. |
| 80 | | | | | | |

Well: 007G61LF
Elev.: 283.04



ENSAFE

# LOG OF BORING 007G62LF



NSA MID-SOUTH
Millington, TN.

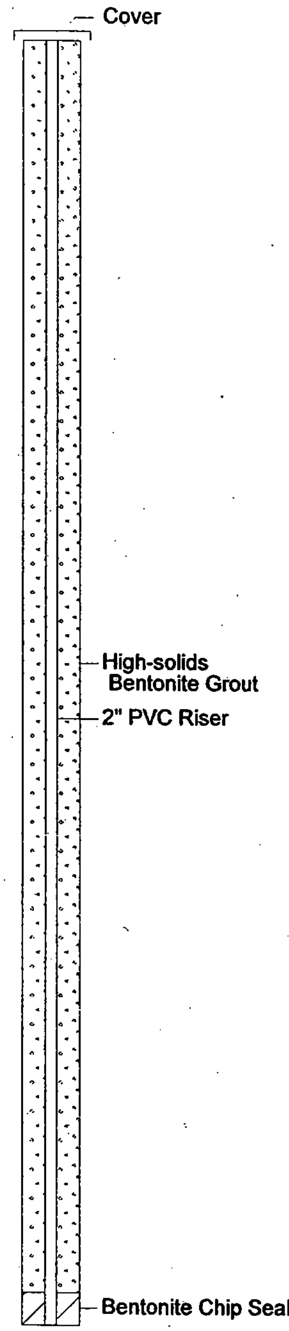
Location: Building N-126

Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 1100 8/3/00 | Northing | : |
| Finished | : 1500 8/3/00 | Easting | : |
| Drilling Method | : Rotasonic | TOC Elevation | : |
| Drilling Company | : Alliance Environmental | Total Depth | : 75 feet |
| Geologist | : Bart Douglas | Well Screen | : 45 to 75 feet |

| Depth in Feet | Surf. Elev. | Samples | % Recovery | FID (ppm) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|
| 0 | 0 | | | | | CONCRETE |
| | | 1 | 100 | 0 | ML | CLAYEY SILT<br>(1-6.5) Dark-brown, moist, and medium stiff. |
| 5 | -5 | 2 | 100 | 0 | | |
| 10 | -10 | 3 | 100 | 0 | | (6.5-19) Brown, soft, and wet. Medium stiffness below 16 feet. |
| 15 | -15 | | | | | |
| 20 | -20 | 4 | 100 | 0 | | (19-23) Reddish-brown and medium stiffness. |
| | | | | | | (23-25) With fine-grained sand throughout. |
| 25 | -25 | | | | CL | SANDY CLAY, brown to orange-brown and stiff with very-fine- to fine-grained sand. |
| 30 | -30 | 5 | 100 | 0 | | |
| | | | | | SC | CLAYEY SAND,<br>(33-38) Orange-brown and fine-grained. |
| 35 | -35 | 6 | 100 | NA | | (38-42) Yellowish-brown to tan and very-fine- to fine-grained. |
| 40 | | | | | | |

Well: 007G62LF
Elev.:

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# LOG OF BORING 007G62LF



ENSAFE

NSA MID-SOUTH
Millington, TN.

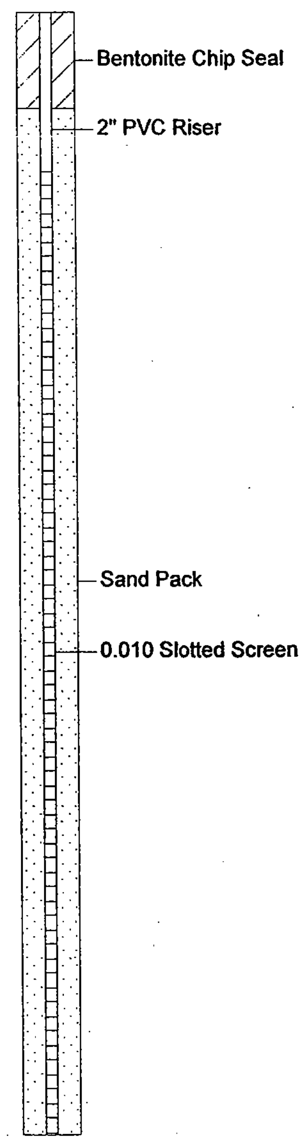
Location: Building N-126

Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 1100 8/3/00 | Northing | : |
| Finished | : 1500 8/3/00 | Easting | : |
| Drilling Method | : Rotasonic | TOC Elevation | : |
| Drilling Company | : Alliance Environmental | Total Depth | : 75 feet |
| Geologist | : Bart Douglas | Well Screen | : 45 to 75 feet |

Well: 007G62LF
Elev.:

| Depth in Feet | Surf. Elev. | Samples | % Recovery | FID (ppm) | GRAPHIC | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| 40 | -40 | | | | | SC | |
| | | 6 | 100 | NA | | SP | SAND, Poorly Graded, tan, and fine- to medium-grained. At 42 is a 1/2-inch thick pinkish-gray clay seam. |
| 45 | -45 | | | | | | |
| | | | | | | SW | SAND, Well Graded, tan to light-brown and medium- to coarse-grained with gravel. |
| 50 | -50 | 7 | 100 | NA | | | |
| 55 | -55 | | | | | GW | GRAVEL, Well Graded, and gray with medium- to coarse-grained sand. |
| 60 | -60 | 8 | 100 | NA | | | |
| | | | | | | SW | SAND, Well Graded, tan, gravely, and coarse-grained. |
| 65 | -65 | | | | | GW | GRAVEL, Well Graded, with coarse-grained sand. |
| 70 | -70 | 9 | 100 | NA | | | |
| 75 | -75 | | | | | ML | CLAYEY SILT, At 75 feet hit 1 inch of mottled light-gray, pinkish-mauve, and orange-brown clayey silt, with mica flakes. Top of Cockfield. |
| 80 | | | | | | | |



# LOG OF BORING 007G63LF



ENSAFE

NSA MID-SOUTH
Millington, TN.

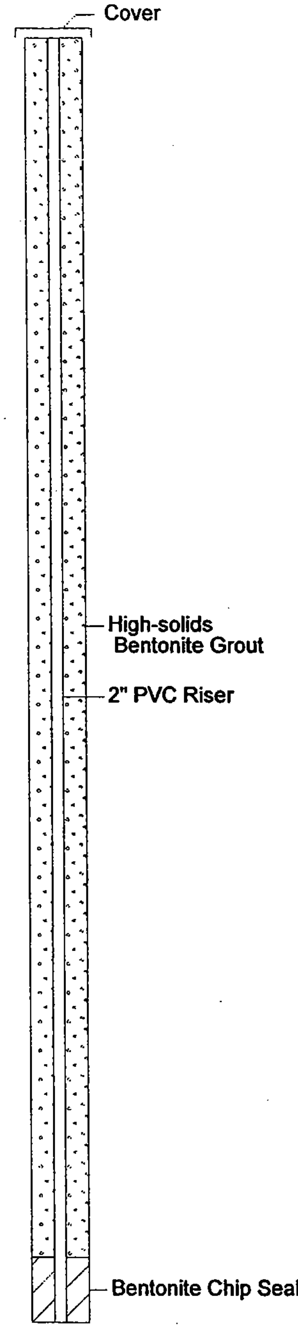
Location: Building N-126

Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 1705 8/3/00 | Northing | : |
| Finished | : 1830 8/3/00 | Easting | : |
| Drilling Method | : Rotasonic | TOC Elevation | : |
| Drilling Company | : Alliance Environmental | Total Depth | : 75 feet |
| Geologist | : Bart Douglas | Well Screen | : 45 to 75 feet |

| Depth in Feet | Surf. Elev. | Samples | % Recovery | FID (ppm) | GRAPHIC | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| 0 | 0 | | | | | | CONCRETE |
| | | 1 | 100 | | | ML | CLAYEY SILT<br>(1-7) Brown and medium to stiff. |
| 5 | -5 | | | | | | |
| | | | | | | | (7-10) Dark-brown and medium to stiff. |
| 10 | -10 | 2 | 100 | | | | (10-18) Brown and soft. |
| 15 | -15 | | | | | | |
| 20 | -20 | 3 | 100 | | | | (18-25) Brown to orange-brown and medium. |
| 25 | -25 | | | | | | (25-26.5) With very-fine-grained sand and medium stiff. |
| | | | | | | CL | SANDY CLAY, mottled red-brown and orange-brown and stiff with fine-grained sand. |
| 30 | -30 | 4 | 100 | | | | |
| | | | | | | SC | CLAYEY SAND, reddish-brown, fine-grained, and stiff. |
| 35 | -35 | | | | | | At 36 feet becoming more yellowish to mustard-brown. |
| | | 5 | 100 | | | | |
| 40 | | | | | | | |

Well: 007G63LF
Elev.:



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# LOG OF BORING 007G63LF



NSA MID-SOUTH
Millington, TN.

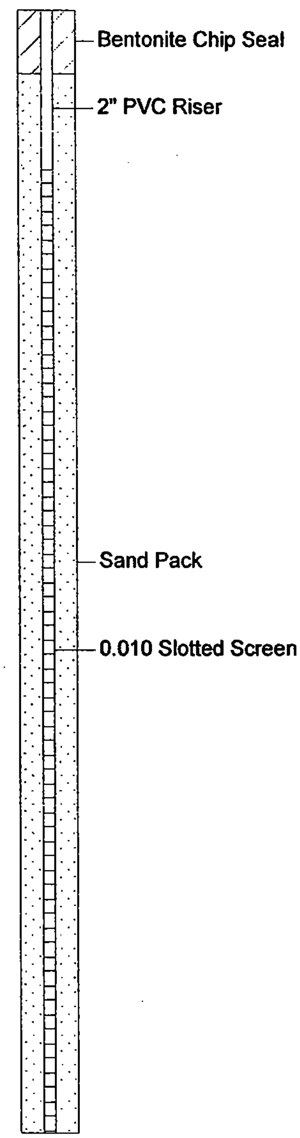
Location: Building N-126

Project #: CTO 0094

| | | | |
|---|---|---|---|
| Started | : 1705 8/3/00 | Northing | : |
| Finished | : 1830 8/3/00 | Easting | : |
| Drilling Method | : Rotasonic | TOC Elevation | : |
| Drilling Company | : Alliance Environmental | Total Depth | : 75 feet |
| Geologist | : Bart Douglas | Well Screen | : 45 to 75 feet |

| Depth in Feet | Surf. Elev. | Samples | % Recovery | FID (ppm) | USCS | DESCRIPTION |
|---|---|---|---|---|---|---|
| 40 | -40 | | | | SC | At 41 feet is a 1-inch thick, light-gray silty clay seam. |
| | | 5 | 100 | | SM | SILTY SAND, brown, and very-fine- to fine-grained. |
| | | | | | SP | SAND, Poorly Graded, tan to light-gray and very-fine- to fine-grained. |
| 45 | -45 | | | | SW | SAND, Well Graded, tan, and medium- to coarse-grained with some gravel. |
| 50 | -50 | 6 | 100 | | GW | GRAVEL, Well Graded, with medium-grained sand. At 52 feet is a 2-inch thick light-gray clay seam. |
| | | | | | SW | SAND, Well Graded, medium- to coarse-grained with gravel. |
| 55 | -55 | | | | GW | GRAVEL, Well Graded, with medium- to coarse-grained sand. |
| 60 | -60 | 7 | 100 | | | |
| | | | | | SW | SAND, Well Graded, tan, and medium-grained with gravel. |
| | | | | | GW | GRAVEL, Well Graded, with medium-grained sand. |
| | | | | | SW | SAND, Well Graded, tan, and medium-grained with gravel. |
| 65 | -65 | | | | GW | GRAVEL, Well Graded, with medium- to coarse-grained sand. |
| 70 | -70 | 8 | 100 | | | |
| 75 | -75 | | | | ML CL | CLAYEY SILT and SILTY CLAY, light-gray to light-tan interbedded thin layers of silty clay and clayey silt with mica flakes. Top of Cockfield. |
| 80 | | | | | | |

Well: 007G63LF
Elev.:

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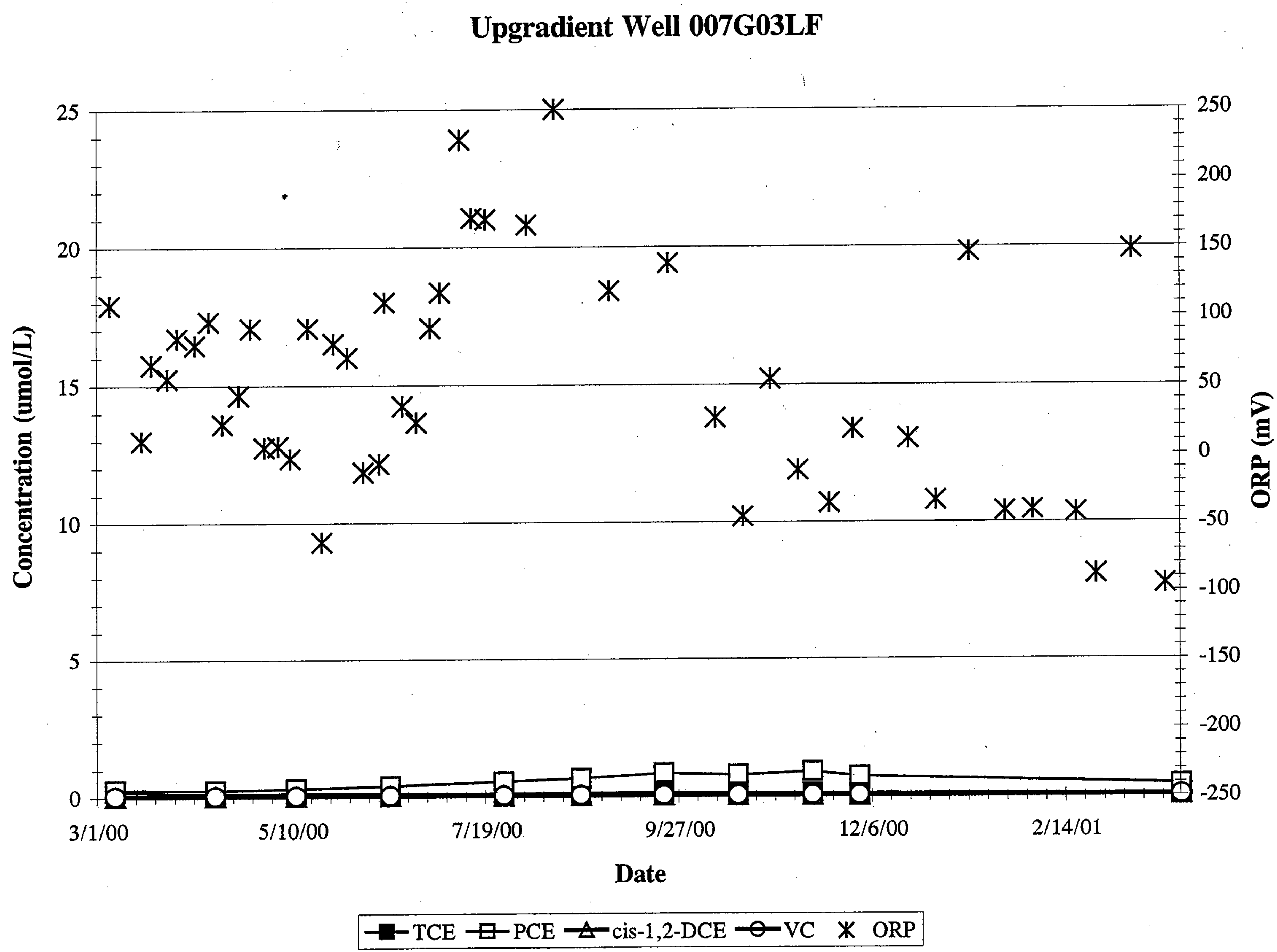
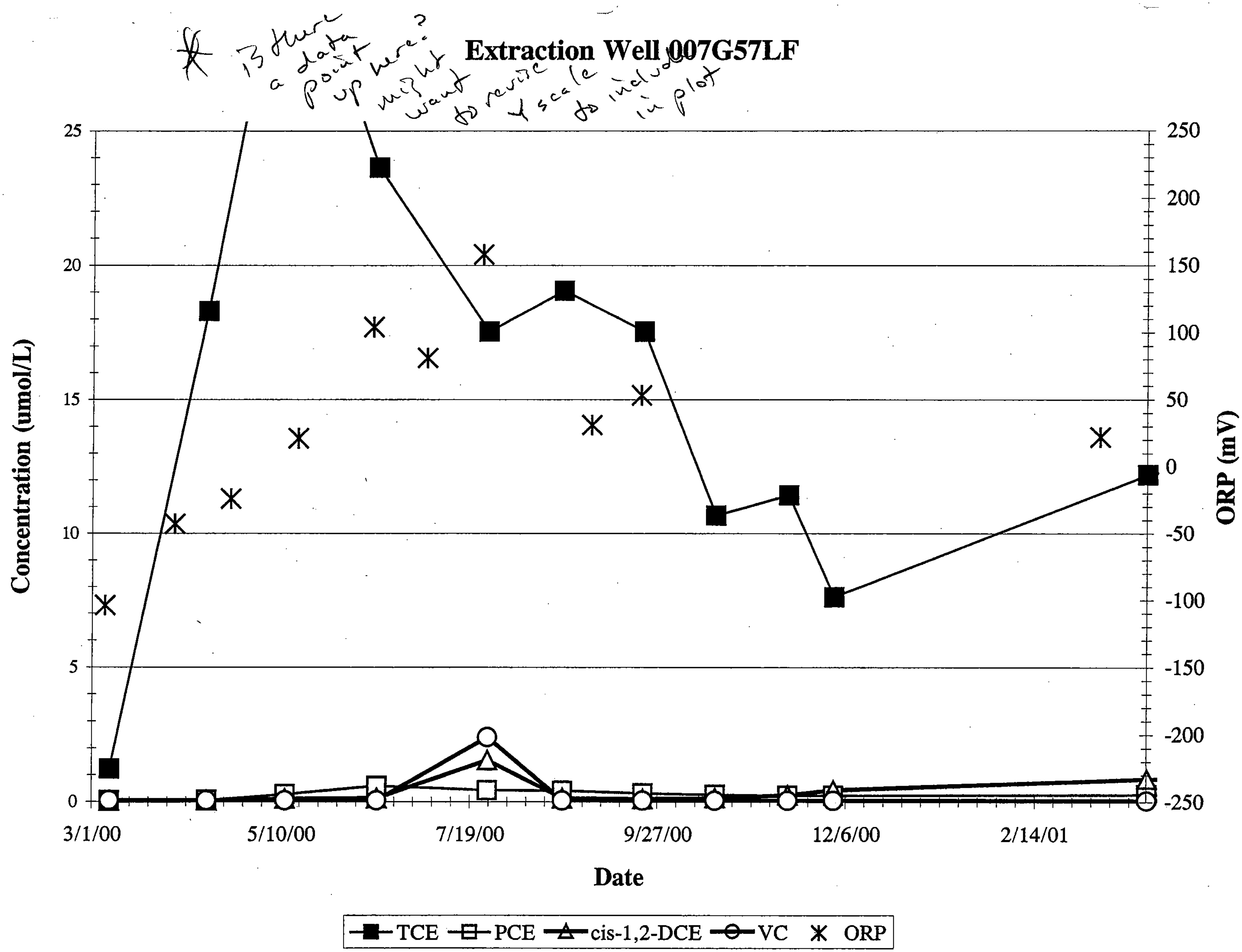
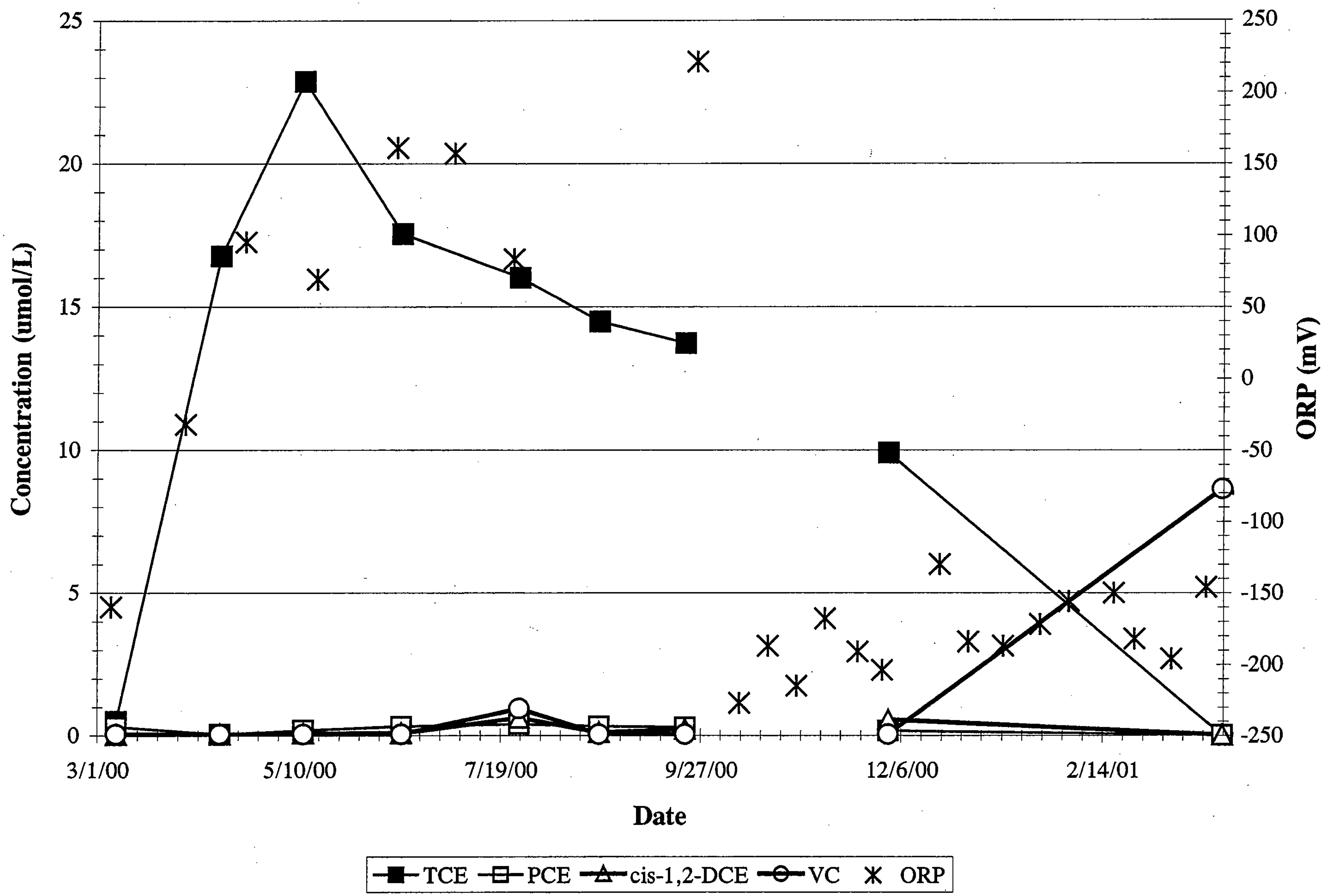
# APPENDIX B
# VOC DATA GRAPHS

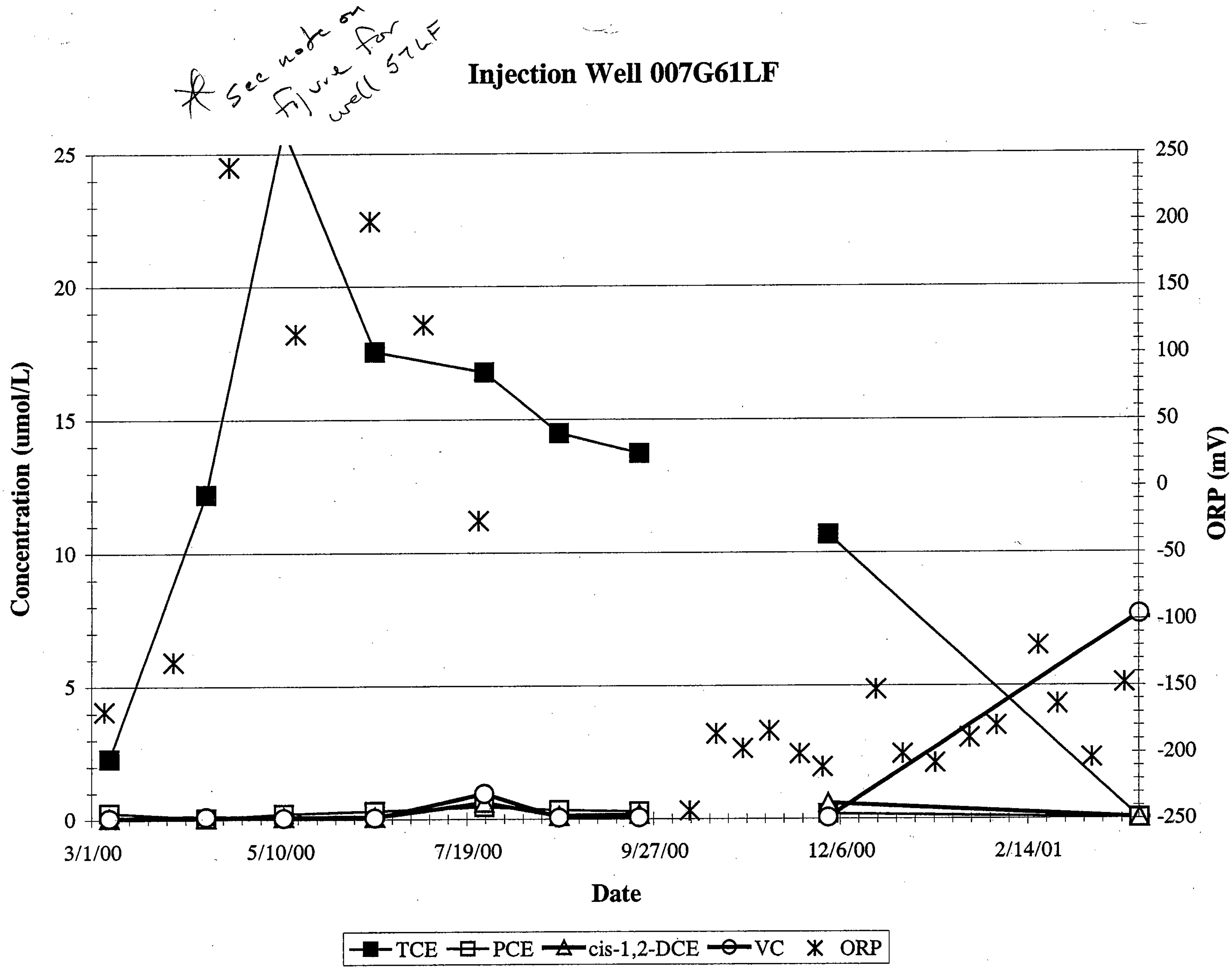

Upgradient Well 007G03LF
Concentration (umol/L)
ORP (mV)
Date
25
20
15
10
5
0
250
200
150
100
50
0
-50
-100
-150
-200
-250
3/1/00
5/10/00
7/19/00
9/27/00
12/6/00
2/14/01
TCE
PCE
cis-1,2-DCE
VC
ORP



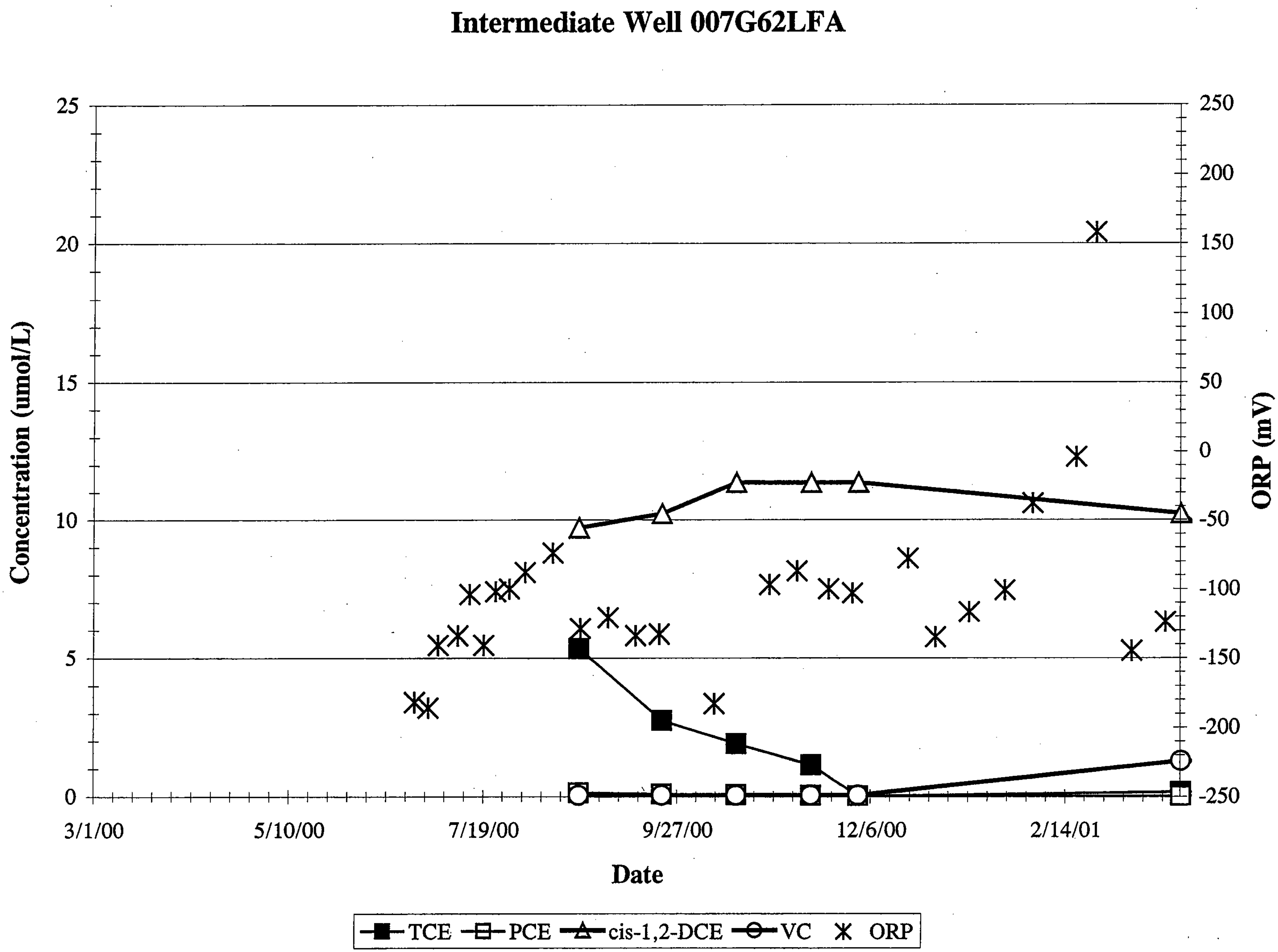
Is there a data point up here? might want to revise Y scale to include in plot
Extraction Well 007G57LF
Concentration (umol/L)
25
20
15
10
5
0
ORP (mV)
250
200
150
100
50
0
-50
-100
-150
-200
-250
3/1/00
5/10/00
7/19/00
9/27/00
12/6/00
2/14/01
Date
TCE
PCE
cis-1,2-DCE
VC
ORP

# Injection Well 007G60LF

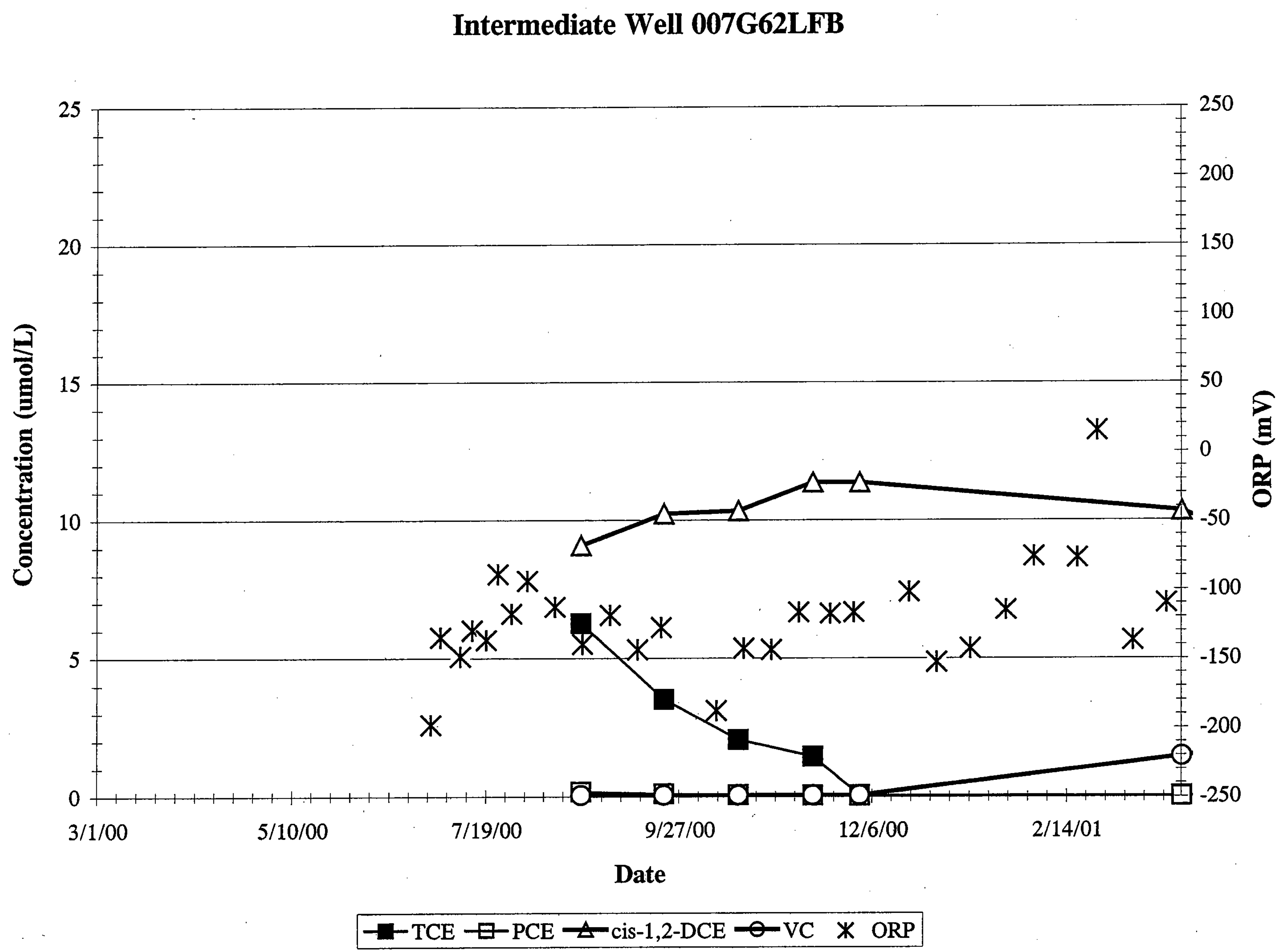




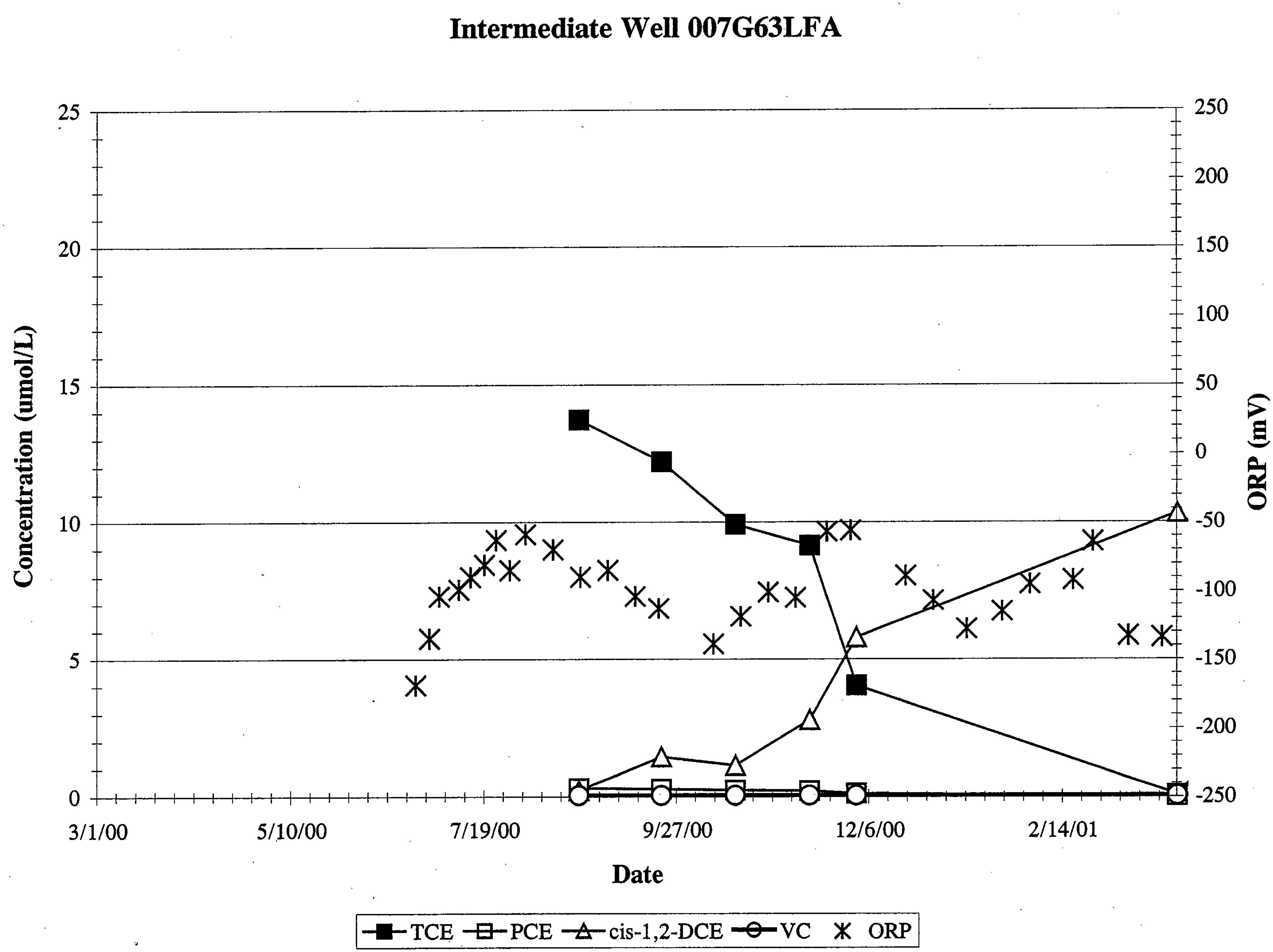
* See note on figure for well 57LF
Injection Well 007G61LF
Concentration (umol/L)
25
20
15
10
5
0
ORP (mV)
250
200
150
100
50
0
-50
-100
-150
-200
-250
3/1/00
5/10/00
7/19/00
9/27/00
12/6/00
2/14/01
Date
TCE
PCE
cis-1,2-DCE
VC
ORP



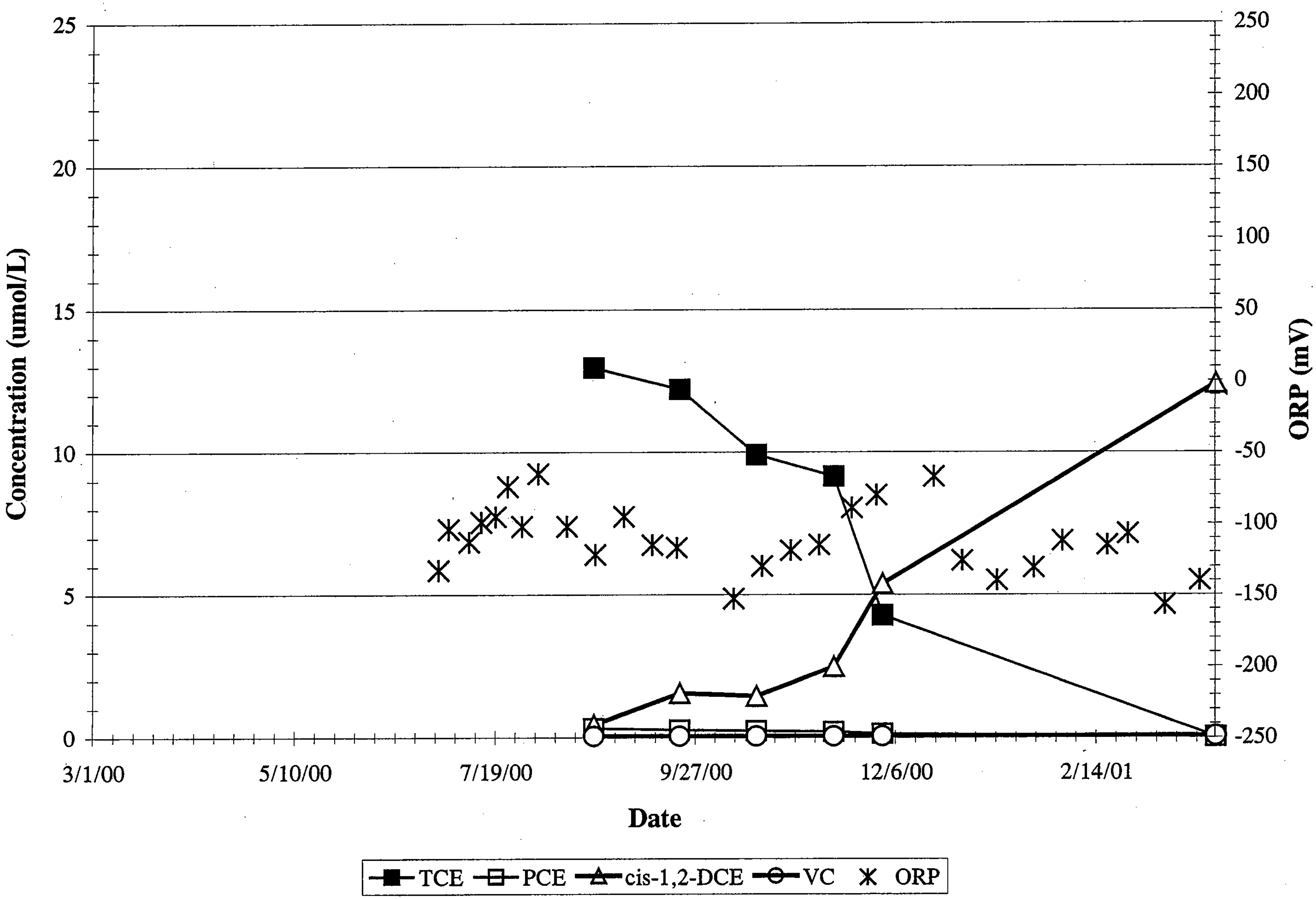
Intermediate Well 007G62LFA
Concentration (umol/L)
ORP (mV)
Date
25
20
15
10
5
0
250
200
150
100
50
0
-50
-100
-150
-200
-250
3/1/00
5/10/00
7/19/00
9/27/00
12/6/00
2/14/01
TCE
PCE
cis-1,2-DCE
VC
ORP

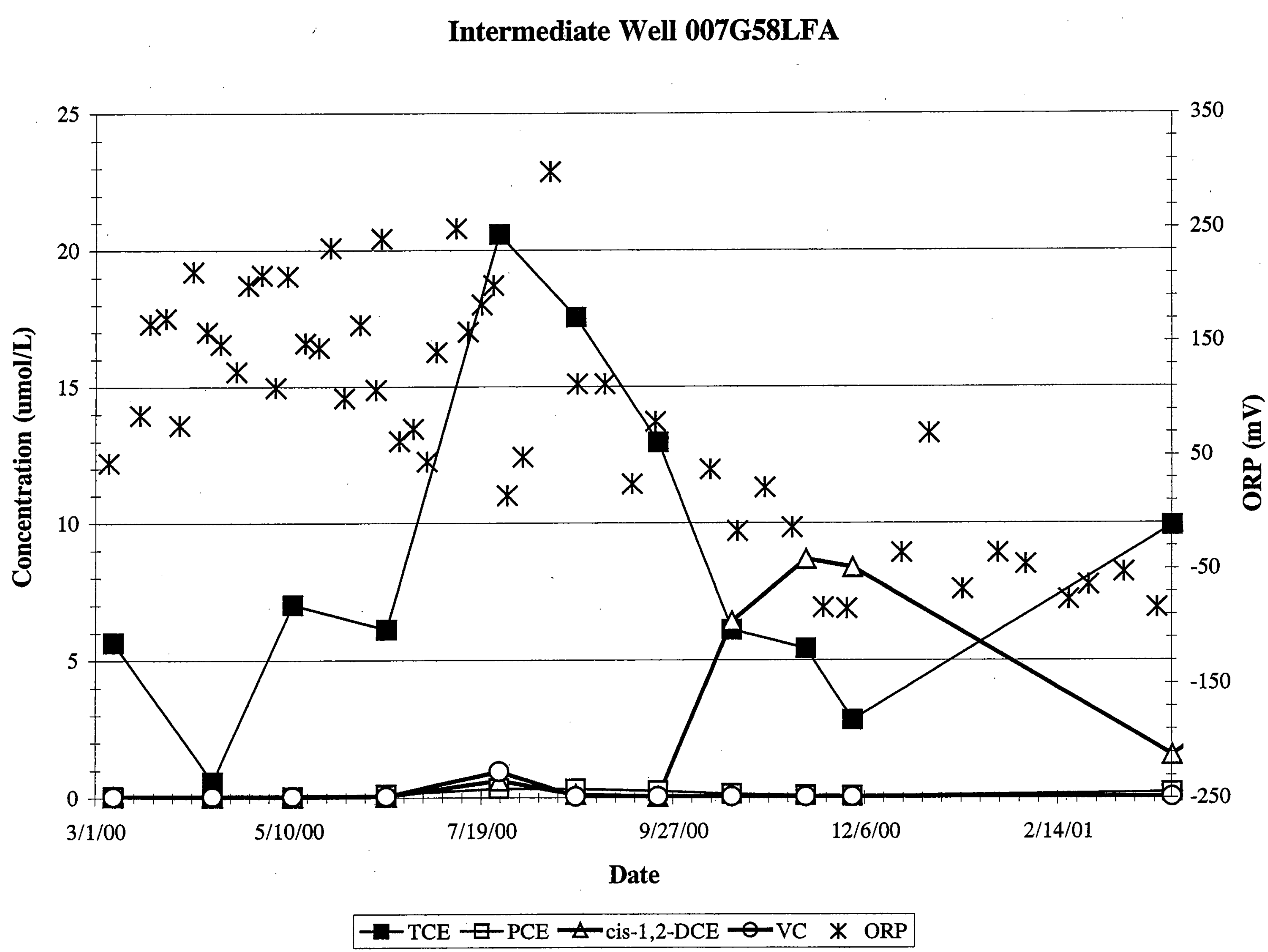


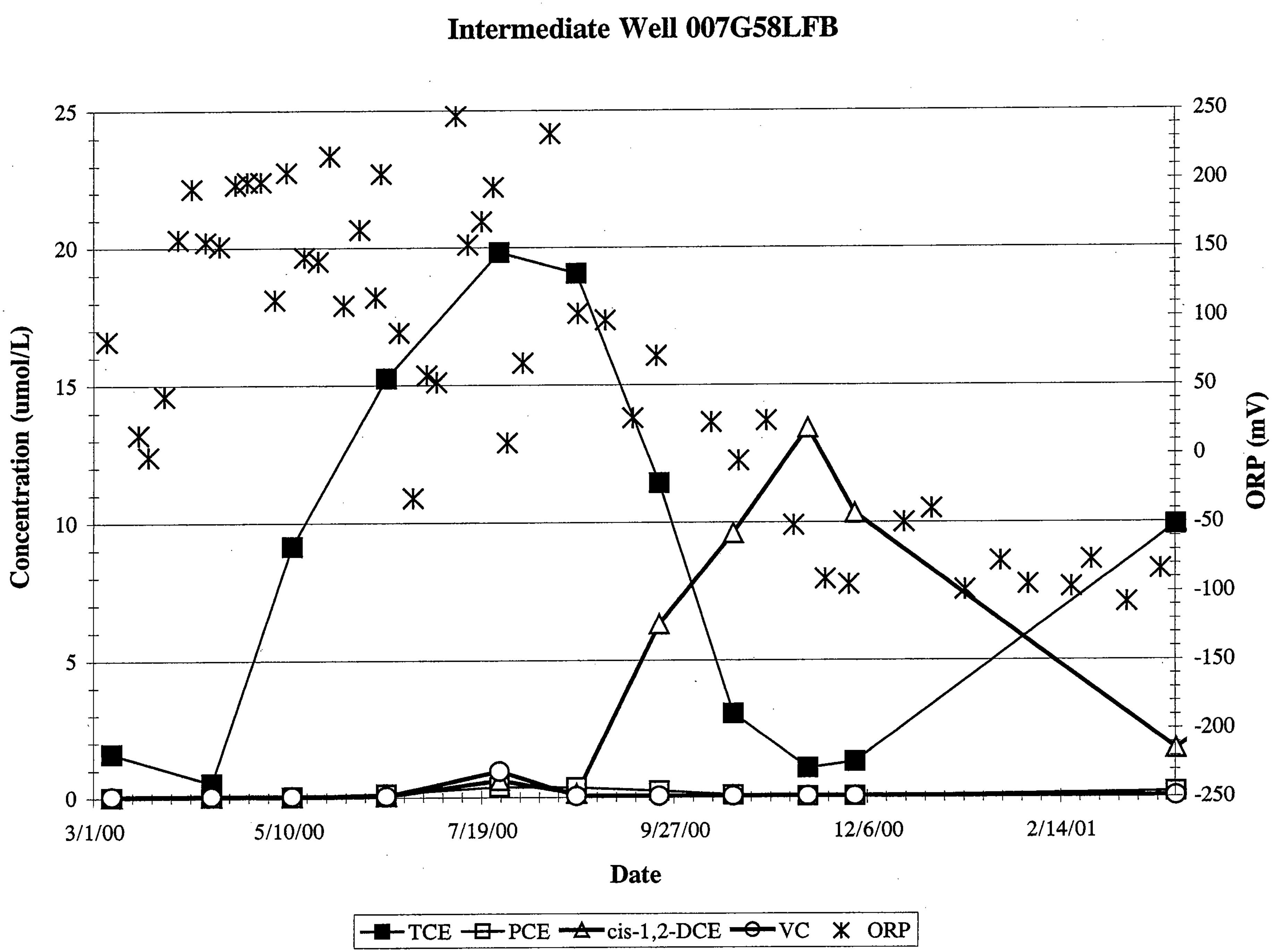
Intermediate Well 007G62LFB
Concentration (umol/L)
ORP (mV)
25
20
15
10
5
0
250
200
150
100
50
0
-50
-100
-150
-200
-250
3/1/00
5/10/00
7/19/00
9/27/00
12/6/00
2/14/01
Date
TCE
PCE
cis-1,2-DCE
VC
ORP


Intermediate Well 007G63LFA
Concentration (umol/L)
25
20
15
10
5
0
ORP (mV)
250
200
150
100
50
0
-50
-100
-150
-200
-250
3/1/00
5/10/00
7/19/00
9/27/00
12/6/00
2/14/01
Date
TCE
PCE
cis-1,2-DCE
VC
ORP

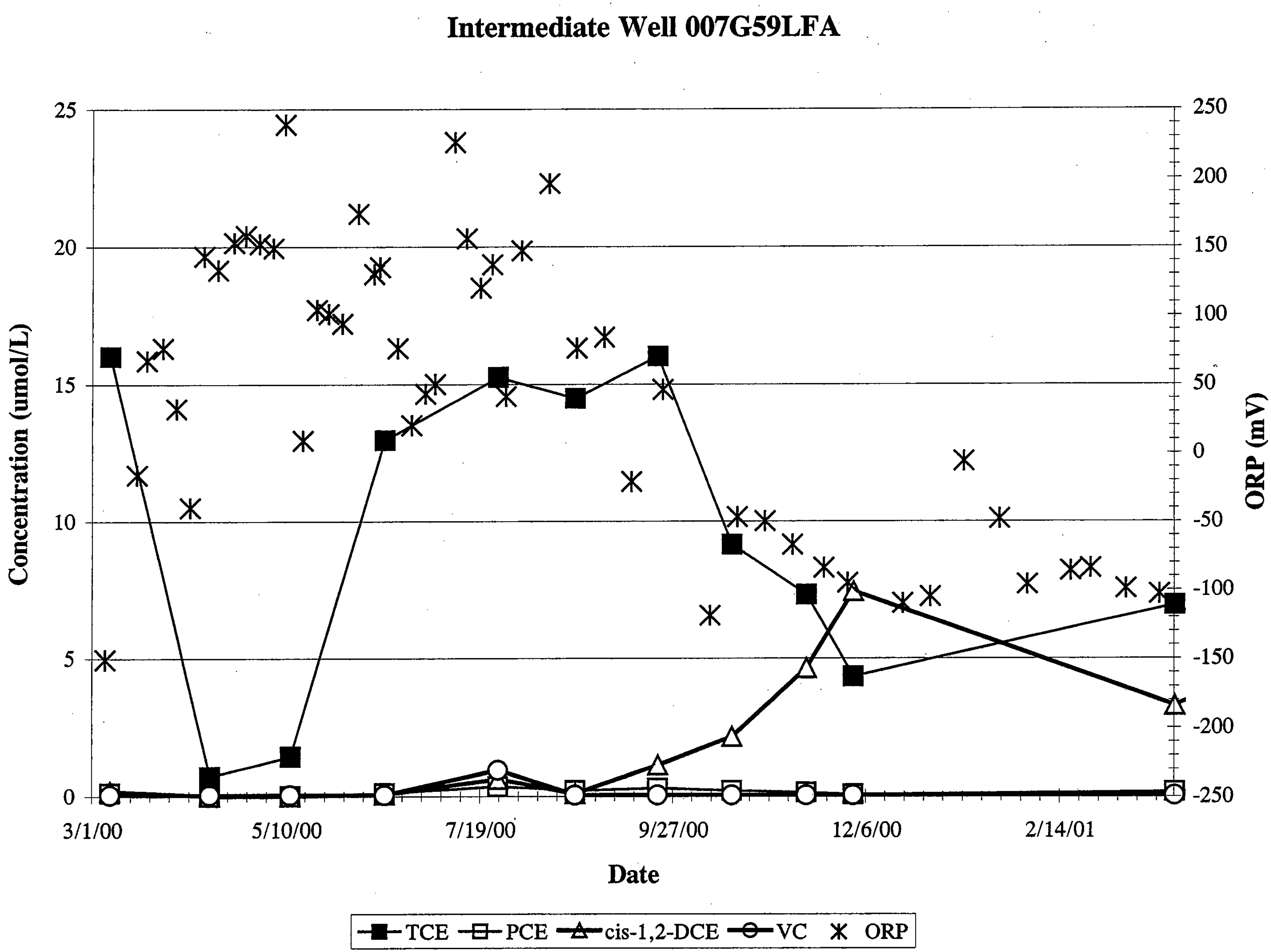
## Intermediate Well 007G63LFB



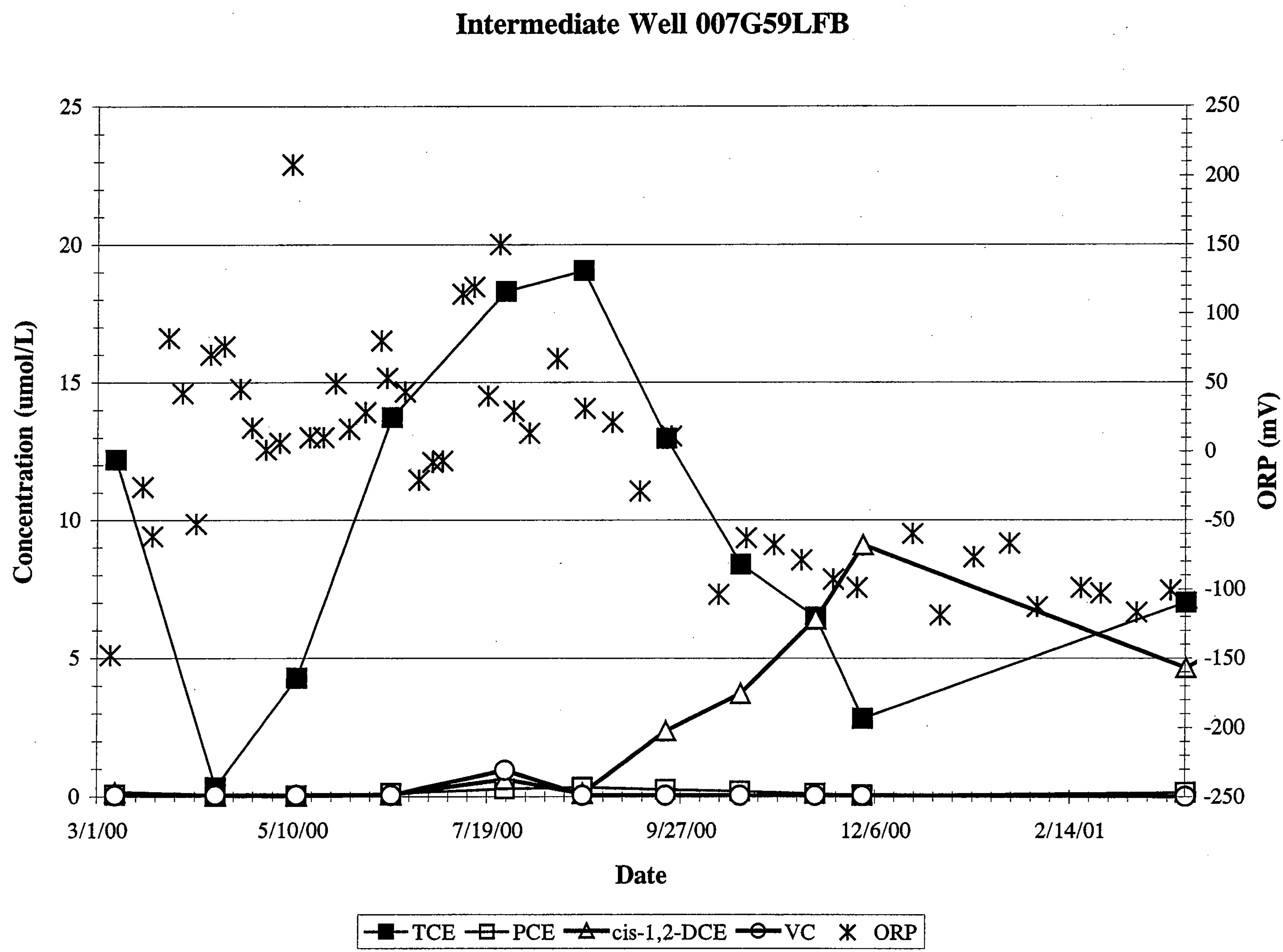

Intermediate Well 007G58LFA
Concentration (umol/L)
ORP (mV)
Date
25
20
15
10
5
0
350
250
150
50
-50
-150
-250
3/1/00
5/10/00
7/19/00
9/27/00
12/6/00
2/14/01
TCE
PCE
cis-1,2-DCE
VC
ORP



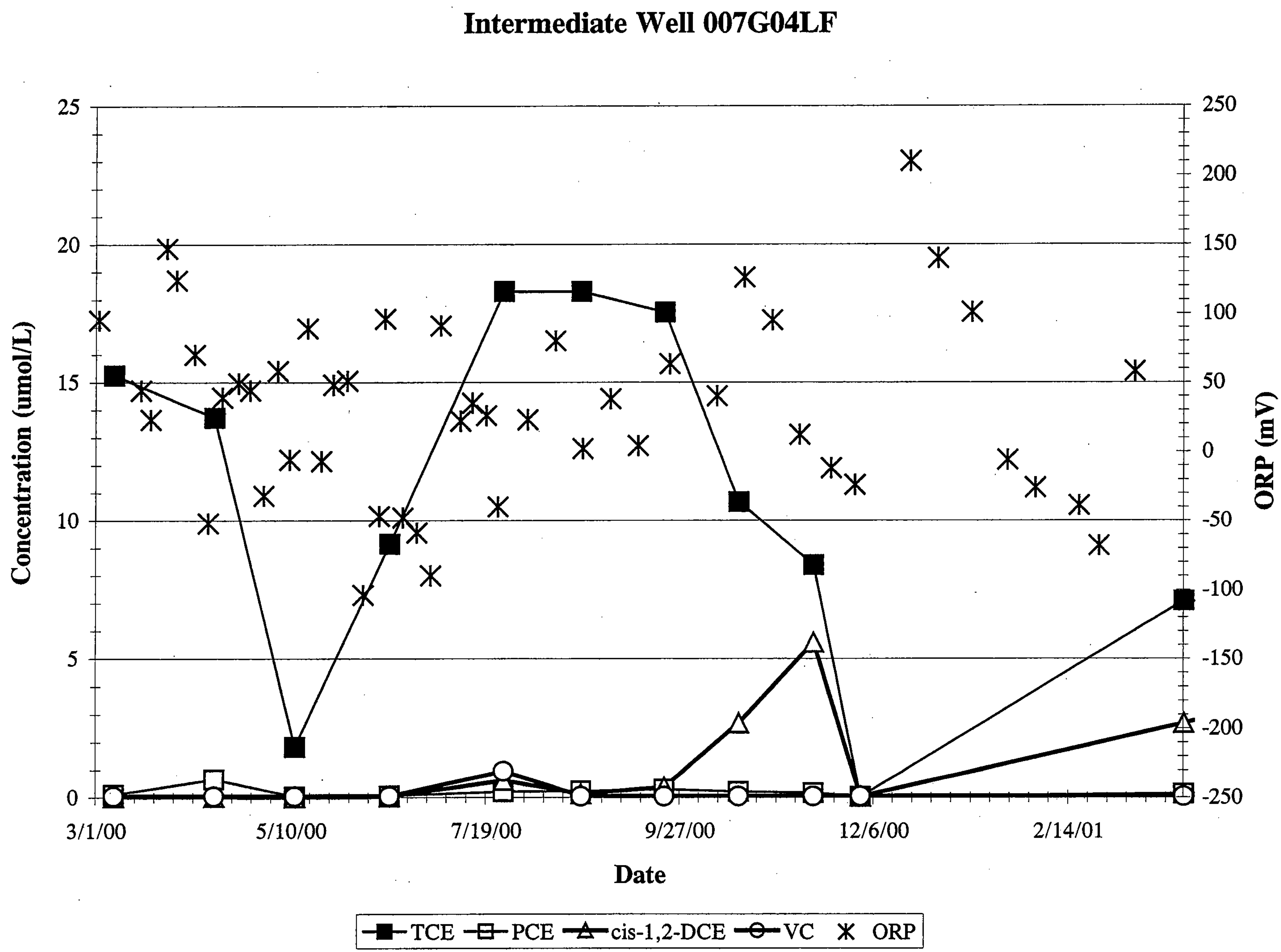
Intermediate Well 007G58LFB
Concentration (umol/L)
ORP (mV)
25
20
15
10
5
0
250
200
150
100
50
0
-50
-100
-150
-200
-250
3/1/00
5/10/00
7/19/00
9/27/00
12/6/00
2/14/01
Date
TCE
PCE
cis-1,2-DCE
VC
ORP



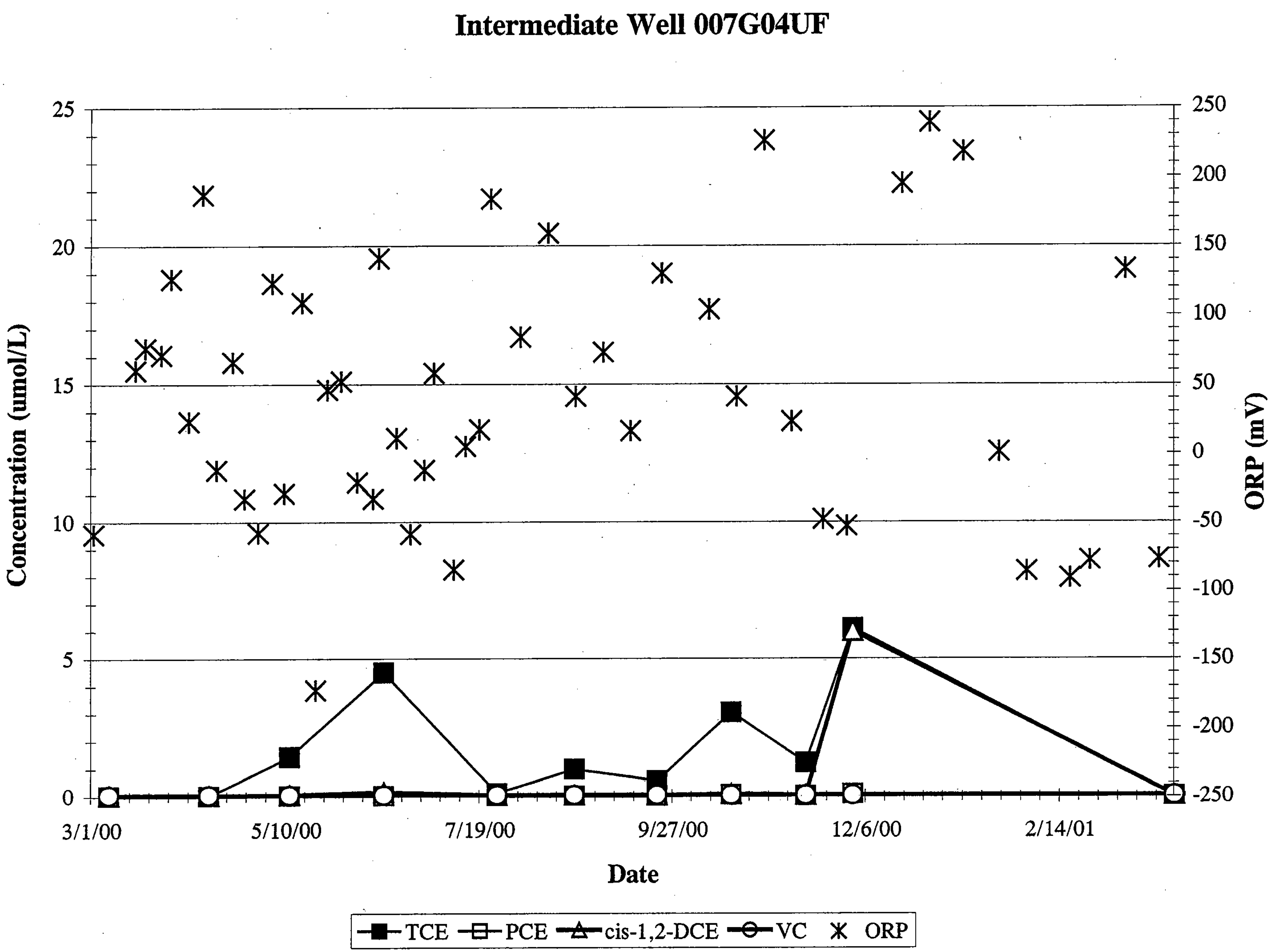
Intermediate Well 007G59LFA
Concentration (umol/L)
ORP (mV)
Date
0
5
10
15
20
25
250
200
150
100
50
0
-50
-100
-150
-200
-250
3/1/00
5/10/00
7/19/00
9/27/00
12/6/00
2/14/01
TCE
PCE
cis-1,2-DCE
VC
ORP



Intermediate Well 007G59LFB
Concentration (umol/L)
ORP (mV)
25
20
15
10
5
0
250
200
150
100
50
0
-50
-100
-150
-200
-250
3/1/00
5/10/00
7/19/00
9/27/00
12/6/00
2/14/01
Date
TCE
PCE
cis-1,2-DCE
VC
ORP

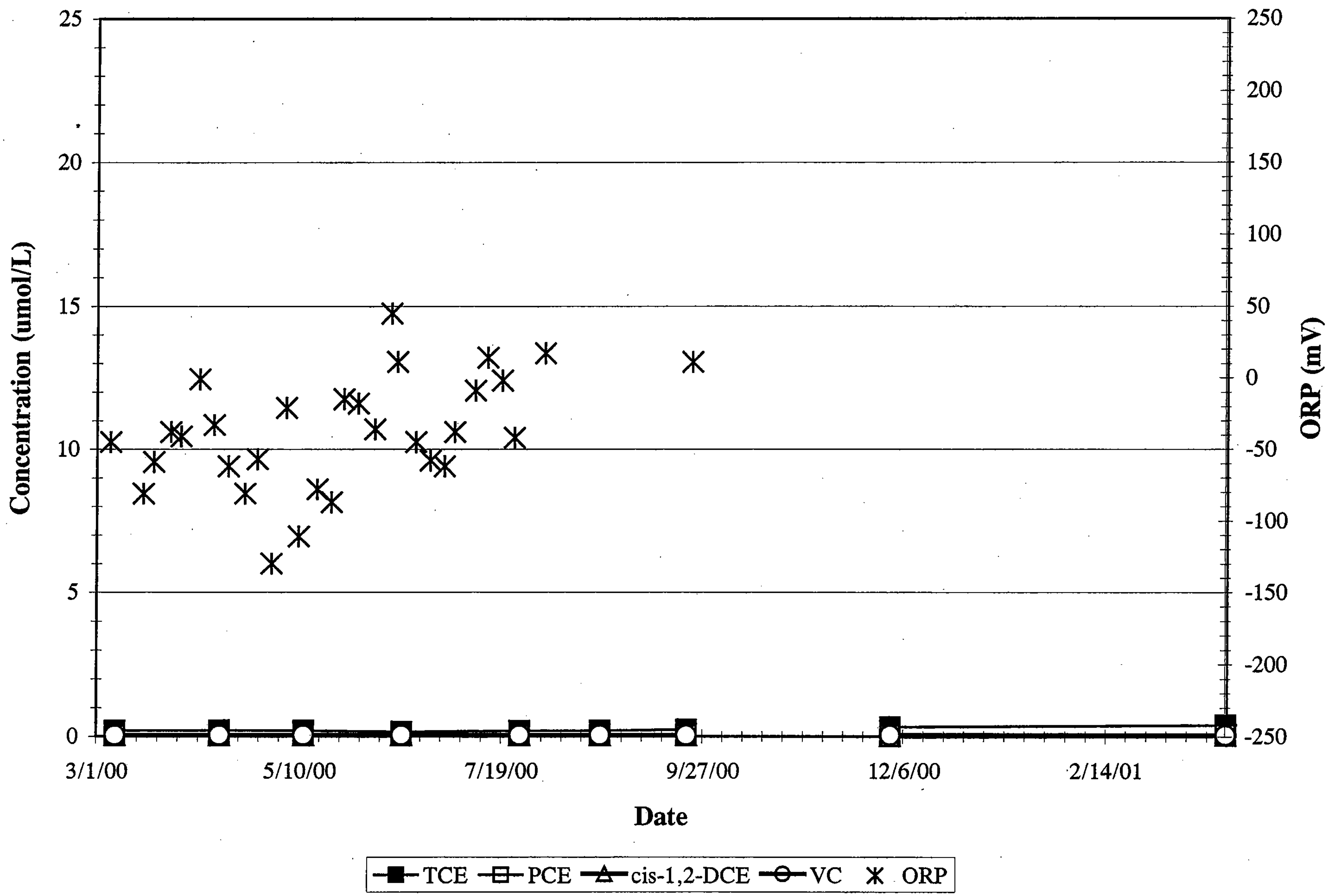


Intermediate Well 007G04LF
Concentration (umol/L)
ORP (mV)
Date
25
20
15
10
5
0
250
200
150
100
50
0
-50
-100
-150
-200
-250
3/1/00
5/10/00
7/19/00
9/27/00
12/6/00
2/14/01
TCE
PCE
cis-1,2-DCE
VC
ORP



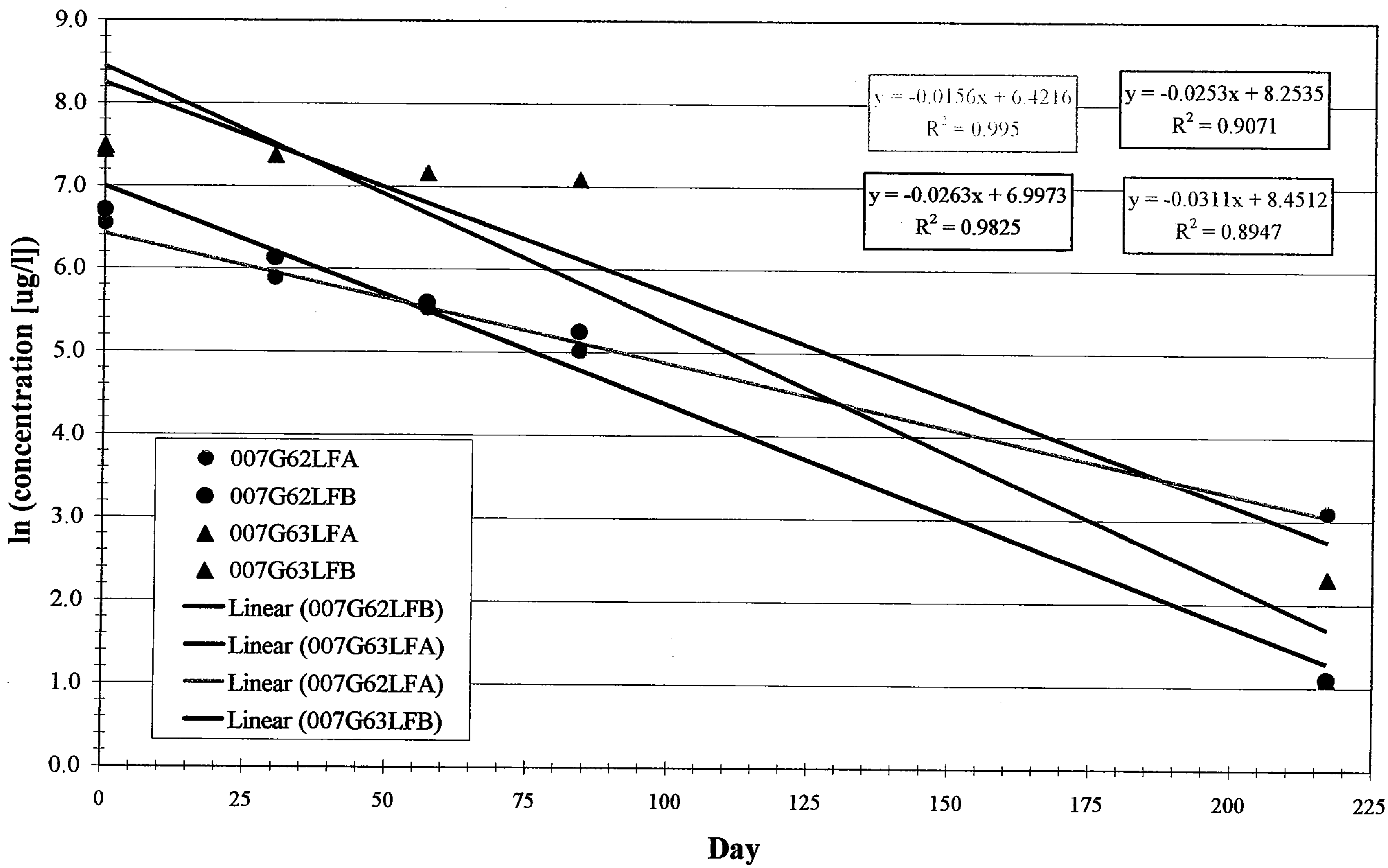
Intermediate Well 007G04UF
Concentration (umol/L)
ORP (mV)
25
20
15
10
5
0
250
200
150
100
50
0
-50
-100
-150
-200
-250
3/1/00
5/10/00
7/19/00
9/27/00
12/6/00
2/14/01
Date
TCE
PCE
cis-1,2-DCE
VC
ORP

## Downgradient Well 007G21LF



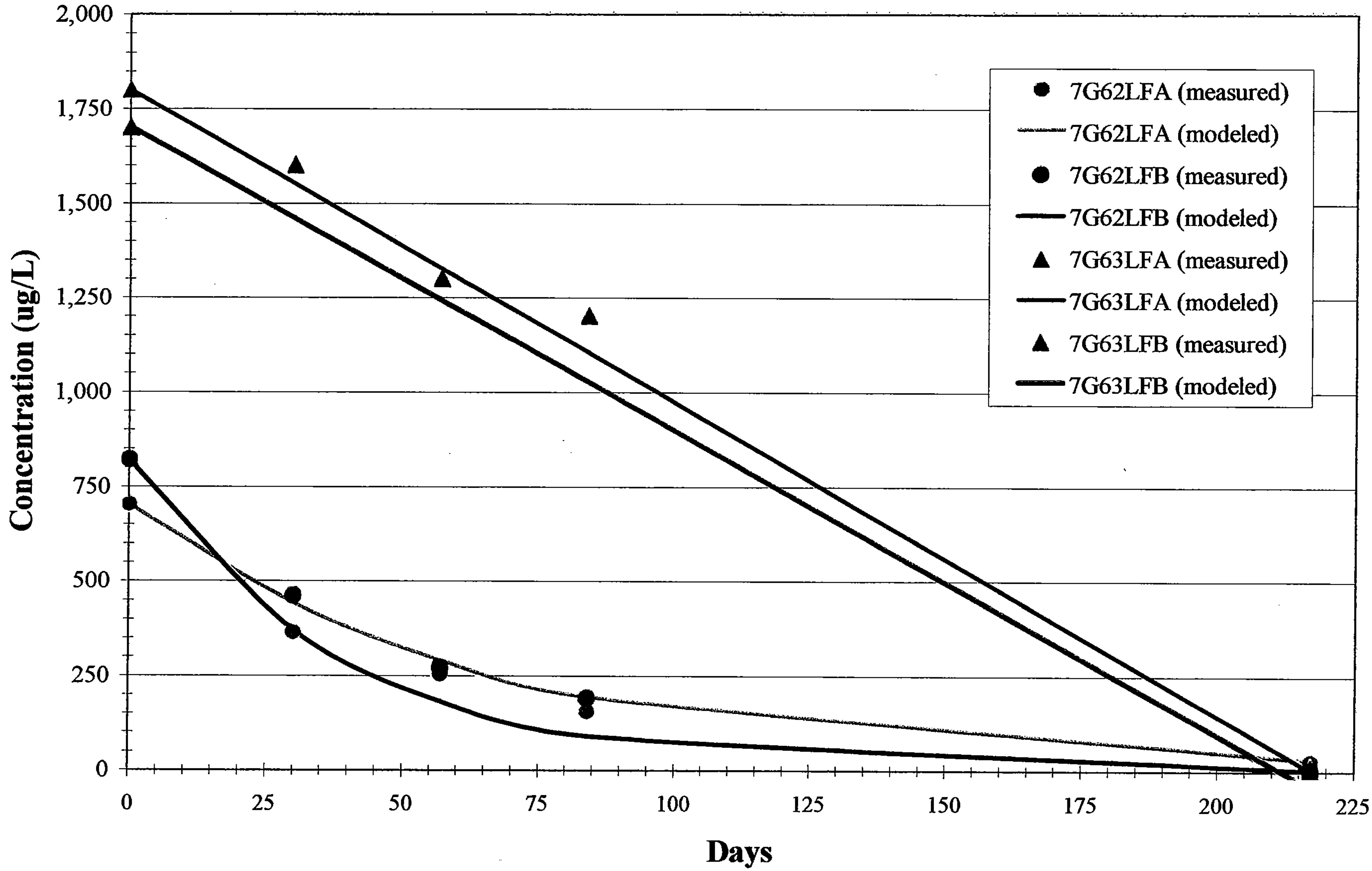
# APPENDIX C
# DEGRADATION RATE GRAPHS

**First-Order TCE Degradation Rates for Select Pilot Study Monitoring Wells**



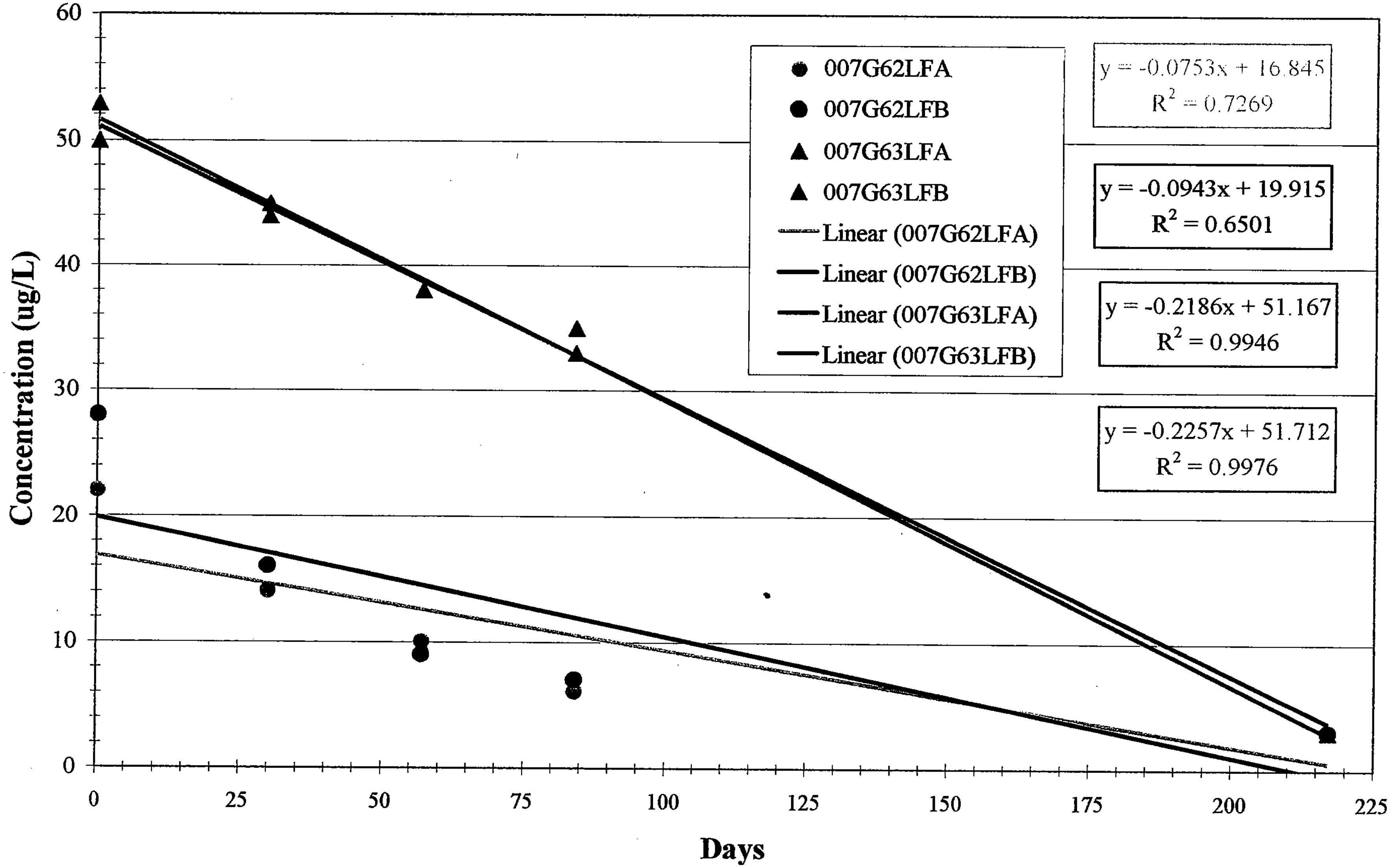

**Note:** December data were considered outliers and excluded from the degradation rate evaluation.

## Measured and Modeled TCE Concentrations for Select Pilot Study Monitoring Wells

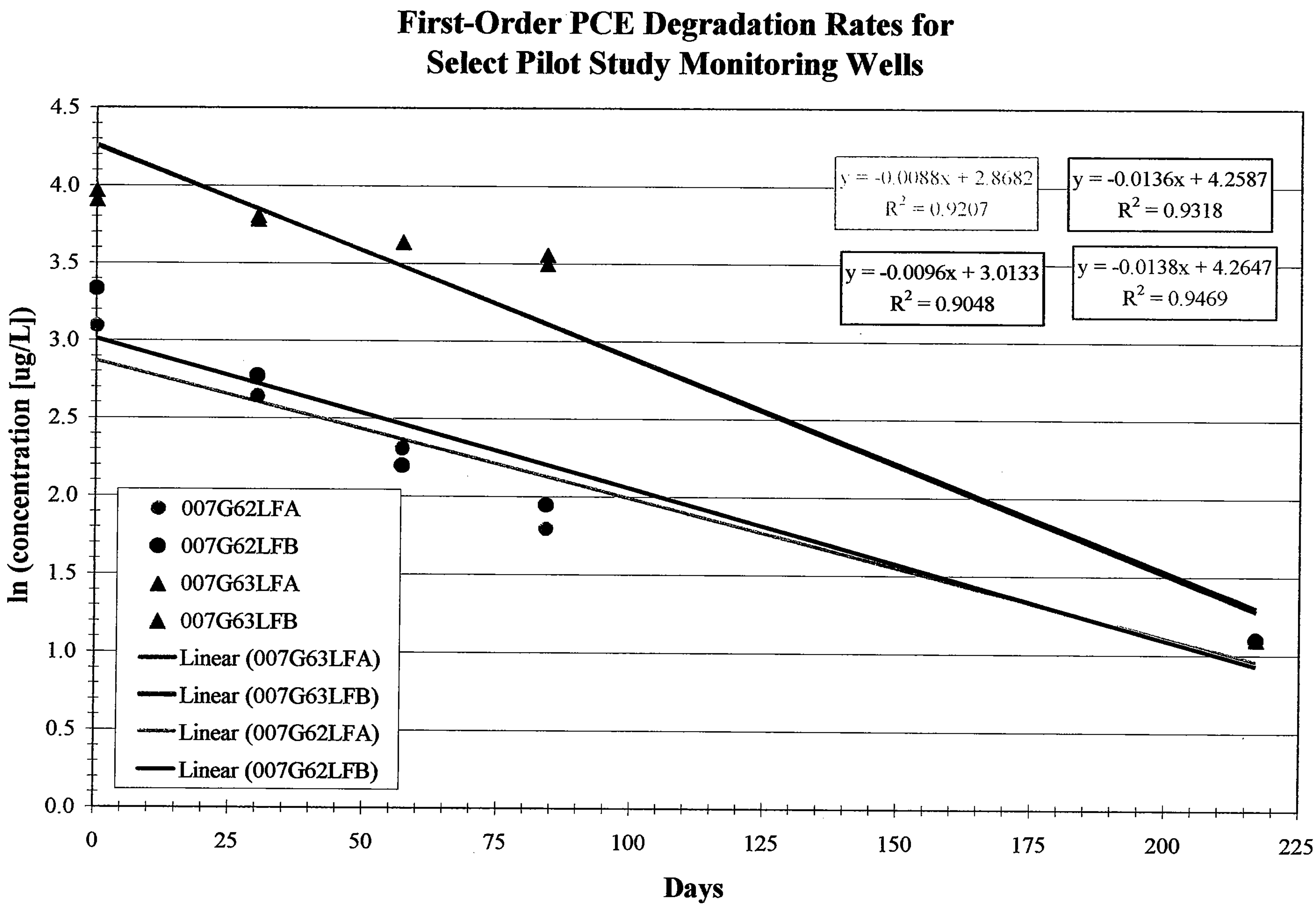



**Note:** December data were considered outliers and excluded from the degradation rate evaluation.

# Zero-Order PCE Degradation Rates for Select Pilot Study Monitoring Wells

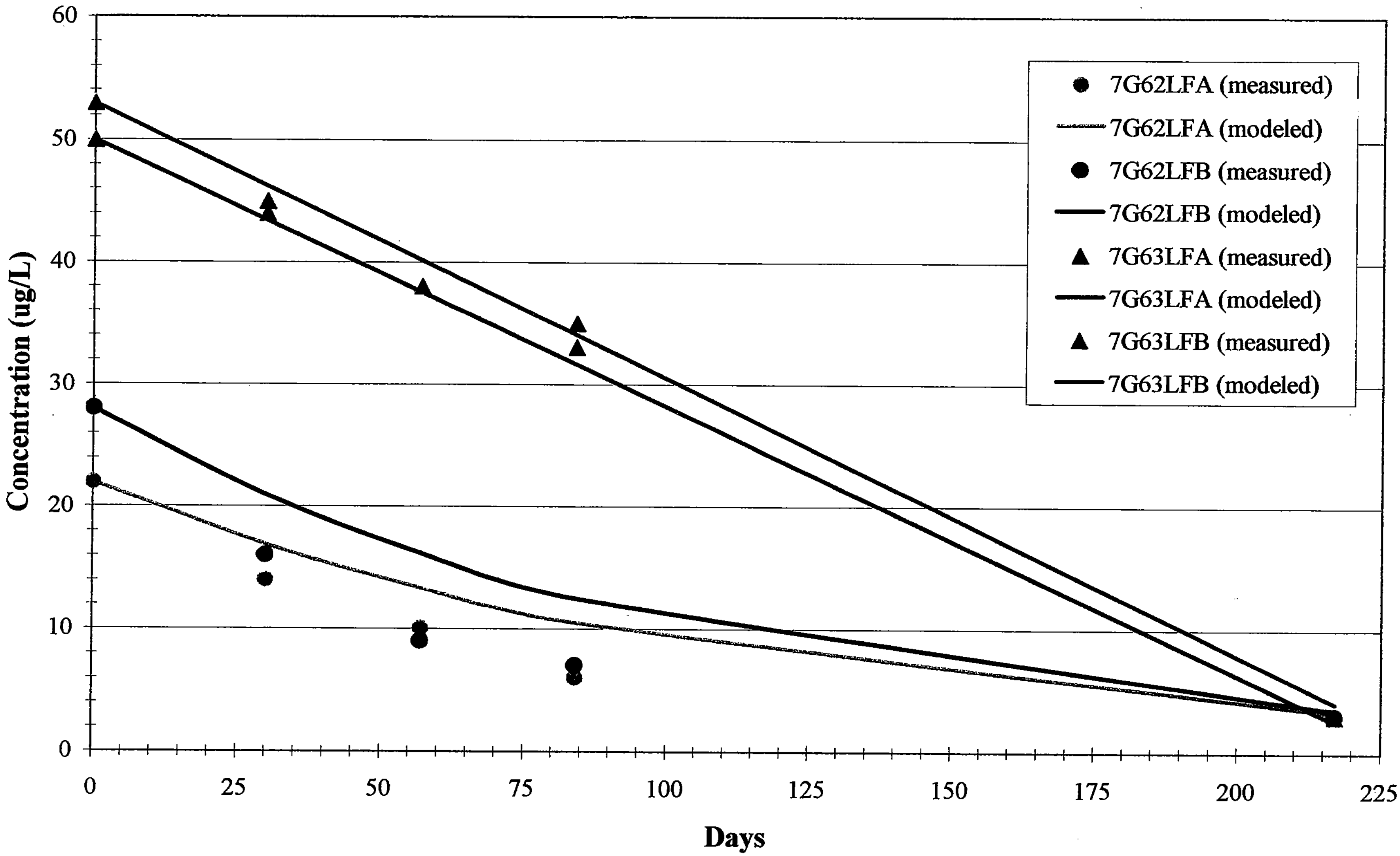



**Note:** December data were considered outliers and excluded from the degradation rate evaluation.

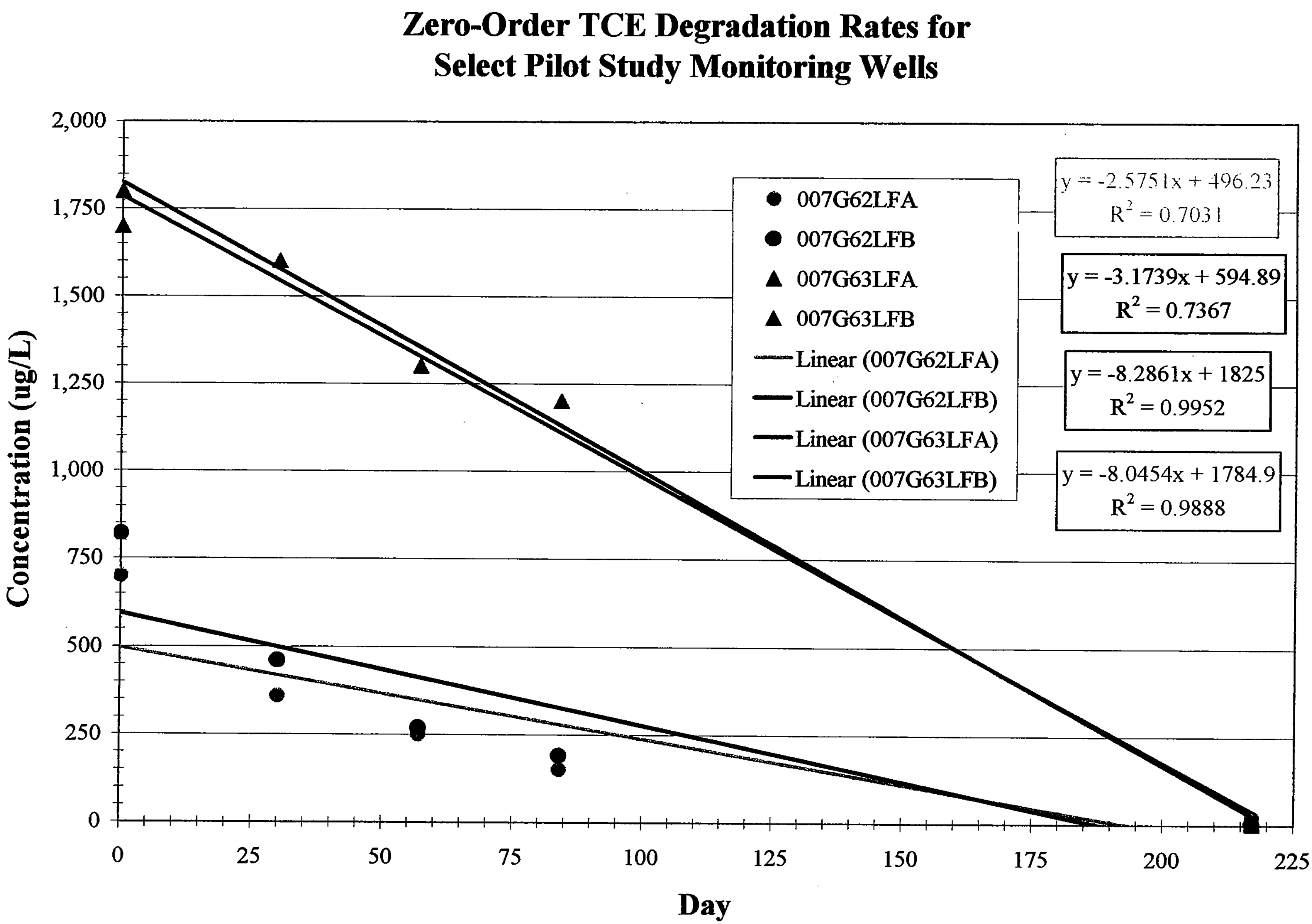



**Note:** December data were considered outliers and excluded from the degradation rate evaluation.

## Measured and Modeled PCE Concentrations for Select Pilot Study Monitoring Wells




**Note:** December data were considered outliers and excluded from the degradation rate evaluation.




**Note:** December data were considered outliers and excluded from the degradation rate evaluation.

# APPENDIX D
# GEOCHEMICAL DATA

**Field Data**

## ORP (mg/L) (field)

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/2/00 | | | | | | | | | | | | | 95 | -59 | |
| 3/7/00 | 108 | -104 | -160 | -169 | | | | | 43 | 82 | -151 | -148 | | | -45 |
| 3/23/00 | 10 | | | | | | | | 85 | 14 | -16 | -26 | 44 | 60 | -81 |
| 3/28/00 | 65 | | | | | | | | 165 | -2 | 67 | -62 | 23 | 76 | -59 |
| 4/5/00 | 55 | | | | | | | | 170 | 42 | 76 | 82 | 147 | 71 | -38 |
| 4/10/00 | 84 | | | | | | | | | | | | 124 | 126 | -41 |
| 4/12/00 | | -43 | -32 | -132 | | | | | 76 | 156 | 32 | 42 | | | |
| 4/19/00 | 79 | | | | | | | | 211 | 193 | -40 | -53 | 70 | 23 | -1 |
| 4/26/00 | 96 | | | | | | | | 158 | 154 | 143 | 70 | -52 | 187 | -33 |
| 5/3/00 | 22 | | | | | | | | 147 | 151 | 133 | 76 | 39 | -12 | -62 |
| 5/11/00 | 43 | -24 | 95 | 240 | | | | | 123 | 196 | 153 | 45 | 49 | 66 | -81 |
| 5/17/00 | 91 | | | | | | | | 199 | 198 | 158 | 17 | 44 | -33 | -57 |
| 5/24/00 | 5 | | | | | | | | 208 | 198 | 152 | 1 | -32 | -58 | -130 |
| 5/31/00 | 6 | | | | | | | | 109 | 112 | 149 | 6 | 58 | 123 | -21 |
| 6/6/00 | -3 | | | | | | | | 207 | 205 | 239 | 208 | -6 | -29 | -111 |
| 6/15/00 | 91 | 21 | 69 | 114 | | | | | 148 | 143 | 9 | 10 | 89 | 109 | -78 |
| 6/22/00 | -64 | | | | | | | | 144 | 140 | 104 | 10 | -7 | -173 | -87 |
| 6/28/00 | 80 | | | | | | | | 232 | 217 | 101 | 49 | 48 | 46 | -15 |
| 7/5/00 | 70 | | | | | | | | 100 | 108 | 94 | 16 | 51 | 52 | -18 |
| 7/13/00 | -13 | | | | | | | | 164 | 163 | 174 | 28 | -104 | -21 | -36 |
| 7/21/00 | -7 | | | | | | | | 107 | 114 | 130 | 80 | -47 | -33 | 45 |
| 7/24/00 | 110 | 104 | 161 | 199 | | | | | 240 | 204 | 135 | 53 | 96 | 141 | 11 |
| 8/2/00 | 35 | | | | | | | | 62 | 88 | 76 | 43 | -48 | 11 | -45 |
| 8/9/00 | 23 | | | | -182 | | -169 | | 73 | -32 | 20 | -21 | -59 | -59 | -58 |
| 8/16/00 | 91 | | | | -186 | -198 | -135 | -133 | 44 | 57 | 43 | -8 | -90 | -12 | -62 |
| 8/21/00 | 117 | 81 | 157 | 121 | -141 | -135 | -104 | -104 | 140 | 52 | 50 | -7 | 91 | 58 | -38 |
| 8/31/00 | 228 | | | | -134 | -149 | -99 | -113 | 249 | 246 | 226 | 114 | 22 | -85 | -9 |
| 9/6/00 | 171 | | | | -104 | -130 | -90 | -99 | 158 | 152 | 156 | 119 | 35 | 5 | 14 |
| 9/13/00 | 170 | | | | -141 | -137 | -81 | -95 | 182 | 169 | 120 | 40 | 26 | 17 | -2 |
| 9/19/00 | 277 | 158 | 83 | -26 | -102 | -89 | -63 | -74 | 199 | 194 | 137 | 150 | -40 | 184 | -42 |
| 9/26/00 | | | | | -100 | -118 | -85 | -102 | 14 | 8 | 41 | 29 | | | |
| 10/4/00 | 166 | | | | -88 | -94 | -59 | -65 | 48 | 66 | 147 | 13 | 23 | 84 | 17 |
| 10/18/00 | 250 | 271 | | | -74 | -113 | -70 | -102 | 299 | 233 | 196 | 67 | 80 | 159 | |
| 11/1/00 | | | | | -129 | -140 | -90 | -122 | 112 | 102 | 76 | 31 | 2 | 41 | |
| 11/15/00 | 118 | 31 | | | -121 | -119 | -85 | -95 | 112 | 97 | 84 | 21 | 38 | 73 | |
| 11/29/00 | | | | | -134 | -144 | -104 | -115 | 24 | 26 | -21 | -29 | 4 | 16 | |
| 12/11/00 | | 53 | | | -133 | -128 | -113 | -117 | 79 | 71 | | | | | |
| 12/15/00 | 138 | | | | | | | | | | 46 | 11 | 63 | 130 | 11 |
| 12/18/00 | | | 221 | 262 | | | | | | | | | | | |
| 1/8/01 | 26 | | -227 | -244 | -183 | -188 | -139 | -153 | 37 | 23 | -119 | -104 | 40 | 104 | |
| 1/22/01 | -46 | | -187 | -186 | | -143 | -119 | -130 | -17 | -5 | -47 | -63 | 126 | 41 | |
| 2/5/01 | 54 | | -215 | -197 | -97 | -144 | -101 | -119 | 21 | 24 | -50 | -68 | 95 | 226 | |
| 2/19/01 | -12 | | -168 | -184 | -87 | -117 | -105 | -115 | -14 | -52 | -67 | -79 | 12 | 23 | |
| 3/7/01 | -36 | | -191 | -201 | -100 | -118 | -57 | -89 | -84 | -91 | -84 | -93 | -12 | -48 | |
| 3/19/01 | 18 | | -204 | -211 | -103 | -117 | -56 | -80 | -85 | -95 | -95 | -99 | -24 | -53 | |

**DO (mg/L) (field)**

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/2/00 | | | | | | | | | | | | | 1.50 | 1.60 | |
| 3/7/00 | | | | | | | | | | | | | | | |
| 3/23/00 | 1.90 | | | | | | | | 3.00 | 3.30 | 1.30 | 1.90 | 1.80 | 1.00 | 0.80 |
| 3/28/00 | 2.20 | | | | | | | | 3.50 | 3.40 | 1.20 | 1.30 | 2.00 | 0.80 | 0.70 |
| 4/5/00 | 0.50 | | | | | | | | 2.10 | 2.30 | 1.70 | 0.70 | 1.80 | | 0.50 |
| 4/10/00 | 2.80 | | | | | | | | | | | | 2.80 | 0.80 | |
| 4/12/00 | 1.30 | 1.00 | 1.20 | 1.00 | | | | | 3.50 | 2.20 | | 0.60 | 2.20 | | 0.70 |
| 4/19/00 | | | | | | | | | 1.70 | 2.10 | 0.80 | | | | 0.60 |
| 4/26/00 | | | | | | | | | | 1.07 | | | 0.20 | | |
| 5/3/00 | 0.80 | | | | | | | | 1.80 | | 0.80 | | | 0.80 | 0.40 |
| 5/11/00 | 0.65 | 0.83 | 0.99 | 0.40 | | | | | 1.37 | 0.30 | 0.64 | 0.43 | 0.90 | 0.69 | 0.15 |
| 5/17/00 | 1.03 | | | | | | | | 0.94 | 0.30 | 0.31 | 0.28 | 0.81 | 0.10 | 0.11 |
| 5/24/00 | 2.13 | | | | | | | | 1.01 | 0.30 | 0.38 | 0.43 | 1.65 | 0.46 | 0.18 |
| 5/31/00 | 1.50 | | | | | | | | 1.20 | 0.23 | 0.43 | 0.35 | 1.98 | 0.15 | 1.01 |
| 6/6/00 | 1.89 | | | | | | | | 0.72 | 0.66 | 0.40 | 0.12 | 0.30 | 0.20 | 0.12 |
| 6/15/00 | 1.94 | 0.49 | 1.86 | | | | | | 0.65 | 0.23 | | | 1.38 | 0.40 | 1.15 |
| 6/22/00 | 1.46 | | | | | | | | 0.46 | 0.09 | 0.25 | 0.13 | 0.45 | 0.06 | 0.12 |
| 6/28/00 | 2.02 | | | | | | | | 0.87 | 0.19 | 0.47 | | 0.17 | 0.12 | 0.14 |
| 7/5/00 | | | | | | | | | | | | | | | |
| 7/13/00 | 0.15 | | | | | | | | 0.42 | 0.25 | 0.48 | 0.12 | 0.32 | 0.17 | 0.13 |
| 7/21/00 | 2.06 | | | | | | | | 0.51 | 0.19 | 0.16 | | | | |
| 7/24/00 | 2.25 | 1.15 | 2.90 | 1.72 | | | | | 1.04 | 0.89 | 0.75 | 0.73 | 1.22 | 0.60 | 0.78 |
| 8/2/00 | 1.22 | | | | | | | | 0.51 | 0.30 | 0.30 | 0.17 | 0.22 | 0.19 | 0.21 |
| 8/9/00 | 0.37 | | | | 0.06 | | 0.12 | | 0.34 | 0.09 | 0.19 | 0.08 | 0.18 | 0.15 | 0.19 |
| 8/16/00 | 0.12 | | | | 0.06 | 0.04 | 0.05 | 0.06 | 0.38 | 0.12 | 0.23 | 0.22 | 0.15 | 0.16 | 0.35 |
| 8/21/00 | 2.80 | 1.83 | 3.59 | | | 0.52 | | | 1.86 | 0.61 | 0.70 | | | | 1.42 |
| 8/31/00 | 1.85 | | | | 0.10 | 0.07 | 0.13 | 0.12 | 0.45 | 0.16 | 0.21 | 0.17 | 0.15 | 0.07 | 0.08 |
| 9/6/00 | 1.33 | | | | 0.09 | 0.06 | 0.08 | 0.13 | 0.28 | 0.11 | 0.22 | 0.12 | 0.14 | 0.10 | 0.11 |
| 9/13/00 | 1.75 | | | | 0.12 | 0.15 | 0.15 | 0.19 | 0.92 | 0.25 | 0.63 | 0.50 | 0.19 | 0.27 | 0.18 |
| 9/19/00 | 3.01 | 1.95 | | | | | | | | | 0.18 | | 2.11 | | |
| 9/26/00 | 1.47 | | | | 0.15 | 0.12 | 0.12 | 0.11 | 0.34 | 0.11 | 0.21 | 0.16 | 0.13 | 0.10 | 0.14 |
| 10/4/00 | 1.44 | | | | 0.16 | 0.11 | 0.13 | 0.14 | 0.32 | 0.19 | 0.24 | 0.18 | 0.24 | 0.19 | 0.21 |
| 10/18/00 | 1.68 | 0.63 | | | 0.54 | 0.20 | | 0.37 | 0.85 | 0.54 | 0.79 | 1.05 | 0.57 | 0.78 | |
| 11/1/00 | | | | | | | | | | | | | | | |
| 11/15/00 | | | | | | 0.49 | | | 0.66 | 0.72 | | 0.78 | 0.72 | 0.74 | |
| 11/29/00 | | | | | 0.24 | 0.13 | 0.19 | 0.11 | 0.17 | 0.08 | 0.28 | 0.10 | 0.09 | 0.08 | |
| 12/11/00 | | | | | 0.26 | | 0.32 | 0.37 | 0.43 | 0.29 | | | | | |
| 12/15/00 | 0.78 | | | | | | | | | | | 0.36 | 1.09 | 0.54 | 0.81 |
| 12/18/00 | | | | 0.67 | | | | | | | | | | | |
| 1/8/01 | | | | | | | | | | | 0.50 | 0.80 | 0.54 | 0.18 | |
| 1/22/01 | 1.17 | | 0.52 | 0.48 | | 0.55 | 0.51 | 0.48 | 0.56 | 0.56 | 0.62 | 0.60 | 0.71 | 0.64 | |
| 2/5/01 | 2.16 | | 0.48 | 0.46 | 0.40 | 0.35 | 0.58 | 0.46 | 0.87 | 0.77 | 0.86 | 0.74 | 1.08 | 0.94 | |
| 2/19/01 | 2.30 | | 0.80 | 0.42 | 0.73 | 0.61 | 0.55 | 0.46 | 0.70 | 0.71 | 0.64 | 0.62 | 0.95 | 0.73 | |
| 3/7/01 | 1.37 | | 0.19 | 0.17 | 0.29 | 0.20 | 0.39 | 0.25 | 0.24 | 0.17 | 0.16 | 0.13 | 0.21 | 0.22 | |
| 3/19/01 | 2.30 | | 0.64 | 0.66 | 0.86 | 0.75 | 0.88 | 0.77 | 0.74 | 0.70 | 0.75 | 0.72 | 0.71 | 0.70 | |

**Ammonia-N (mg/L) (field)**

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/2/00 | | | | | | | | | | | | | 0.24 | 0.48 | |
| 3/7/00 | 0.24 | 0.84 | 1.20 | 0.48 | | | | | 0.60 | 0.72 | 0.60 | 0.48 | | | 0.96 |
| 3/23/00 | 0.24 | | | | | | | | 0.60 | 0.60 | 0.48 | 0.48 | 0.72 | 0.48 | 0.72 |
| 3/28/00 | 0.48 | | | | | | | | 0.36 | 0.24 | 0.36 | 0.48 | 0.60 | 0.24 | 0.48 |
| 4/5/00 | 0.48 | | | | | | | | 0.36 | 0.48 | 0.48 | 0.60 | 0.72 | 0.60 | 0.72 |
| 4/10/00 | 0.60 | | | | | | | | | | | | 0.84 | 0.96 | |
| 4/12/00 | 0.72 | 0.84 | 1.20 | 3.60 | | | | | 0.12 | 0.36 | 1.20 | 0.48 | 0.96 | | 0.96 |
| 4/19/00 | | | | | | | | | 0.45 | 0.48 | 0.36 | 0.72 | 0.84 | 0.60 | 0.60 |
| 4/26/00 | 0.48 | | | | | | | | 0.36 | 0.36 | 0.60 | 0.72 | 1.32 | 0.36 | 0.72 |
| 5/3/00 | 0.72 | | | | | | | | 0.36 | 0.48 | 0.60 | 0.48 | | 0.48 | 0.84 |
| 5/11/00 | 0.36 | 0.72 | 0.84 | 0.60 | | | | | 0.36 | 0.24 | 0.60 | 0.48 | 0.24 | 0.48 | 1.44 |
| 5/17/00 | 0.84 | | | | | | | | 0.36 | 0.60 | 0.84 | 0.60 | 0.48 | 0.24 | 0.96 |
| 5/24/00 | 0.84 | | | | | | | | 0.48 | 0.24 | 1.20 | 1.08 | 1.56 | 0.36 | 0.60 |
| 5/31/00 | 0.72 | | | | | | | | 0.00 | 0.24 | 2.16 | 2.40 | 1.44 | 0.60 | 0.12 |
| 6/6/00 | 0.72 | | | | | | | | 0.36 | 0.48 | 2.28 | 1.08 | 1.56 | 0.48 | 0.36 |
| 6/15/00 | 0.36 | 0.60 | 0.72 | 0.96 | | | | | 0.48 | 0.48 | 0.72 | 0.12 | 0.00 | 0.24 | 0.96 |
| 6/22/00 | 0.48 | | | | | | | | 0.00 | 0.48 | 1.08 | 0.78 | 1.68 | 0.60 | 0.48 |
| 6/28/00 | 0.72 | | | | | | | | 0.48 | 0.00 | 1.44 | 0.72 | 1.92 | 0.48 | 0.48 |
| 7/5/00 | 0.96 | | | | | | | | 0.60 | 0.48 | 1.20 | 1.44 | 2.04 | 0.60 | 0.60 |
| 7/13/00 | 0.96 | | | | | | | | 0.00 | 0.00 | 1.20 | 1.68 | 1.56 | 0.72 | 0.72 |
| 7/21/00 | 1.08 | | | | | | | | 0.72 | 0.72 | 1.92 | 1.80 | 1.68 | 0.60 | 0.84 |
| 7/24/00 | 0.84 | 0.84 | 0.60 | 0.72 | | | | | 0.72 | 0.60 | 0.96 | 0.60 | 0.60 | 0.72 | 1.08 |
| 8/2/00 | 0.84 | | | | | | | | 0.60 | 0.60 | 0.96 | 0.72 | 1.68 | 0.60 | 0.84 |
| 8/9/00 | 0.84 | | | | 0.48 | | 0.96 | | 0.60 | 0.72 | 0.84 | 0.60 | 2.04 | 0.72 | 0.84 |
| 8/16/00 | 1.08 | | | | 0.60 | 0.72 | 0.96 | 0.84 | 0.60 | 0.60 | 0.72 | 0.84 | 2.16 | 0.72 | 0.84 |
| 8/21/00 | 0.48 | 0.60 | 0.72 | 0.72 | 0.48 | 0.60 | 0.96 | 0.84 | 0.12 | 0.48 | 0.24 | 0.12 | 0.84 | 0.36 | 1.08 |
| 8/31/00 | 0.84 | | | | 0.84 | 0.96 | 0.84 | 1.08 | 0.36 | 0.60 | 0.48 | 0.48 | 0.72 | 0.48 | 0.72 |
| 9/6/00 | 0.48 | | | | 0.72 | 0.72 | 0.84 | 0.96 | 0.60 | 0.36 | 0.36 | 0.24 | 0.84 | 0.72 | 0.96 |
| 9/13/00 | 0.48 | | | | 0.60 | 0.96 | 0.96 | 0.96 | 0.60 | 0.48 | 0.60 | 0.72 | 0.96 | 0.60 | 0.96 |
| 9/19/00 | 0.48 | 0.48 | 1.44 | 1.20 | 0.84 | 0.96 | 0.96 | 0.96 | 0.60 | 0.60 | 0.72 | 0.48 | 0.72 | 0.48 | 0.96 |
| 9/26/00 | 0.24 | | | | 0.84 | 0.96 | 1.20 | 1.44 | 0.48 | 0.60 | 0.36 | 0.48 | 0.72 | 0.36 | 1.20 |
| 10/4/00 | 0.48 | | | | 0.72 | 0.84 | 0.62 | 0.84 | 0.36 | 0.48 | 0.72 | 0.48 | 1.20 | 0.72 | 0.96 |
| 10/18/00 | | 0.72 | | | 0.72 | 0.84 | 0.96 | 0.96 | 0.60 | 0.60 | 0.48 | 0.60 | 0.48 | 0.60 | |
| 11/1/00 | | | | | 0.96 | 1.08 | 1.08 | 1.08 | 0.48 | 0.72 | 0.84 | 0.60 | 1.80 | 0.60 | |
| 11/15/00 | | 0.60 | | | 0.84 | 0.72 | 0.96 | 0.96 | 0.36 | 0.48 | 0.48 | 0.60 | 0.48 | 0.36 | |
| 11/29/00 | | | | | 1.08 | 0.48 | 0.84 | 1.20 | 0.84 | 0.60 | 0.72 | | 1.92 | 0.48 | |
| 12/11/00 | | 0.60 | | | 0.84 | 0.96 | 1.44 | 1.60 | 0.60 | 0.48 | | | | | |
| 12/15/00 | 0.48 | | | | | | | | | | 0.60 | 0.72 | 0.60 | 0.48 | 0.96 |
| 12/18/00 | | | 3.60 | 3.60 | | | | | | | | | | | |
| 1/8/01 | | | | | | | | | | | | | | | |
| 1/22/01 | | | | | | | | | | | | | | | |
| 2/5/01 | | | | | | | | | | | | | | | |
| 2/19/01 | | | | | | | | | | | | | | | |
| 3/7/01 | | | | | | | | | | | | | | | |
| 3/19/01 | | | | | | | | | | | | | | | |

## $CO_2$ (mg/L) (field)

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/2/00 | | | | | | | | | | | | | 10 | 8 | |
| 3/7/00 | 56 | 40 | 22 | | | | | | 38 | 24 | 30 | 36 | | | 48 |
| 3/23/00 | 44 | | | | | | | | 32 | 16 | 22 | | 28 | 48 | 8 |
| 3/28/00 | 32 | | | | | | | | 28 | 12 | 20 | | 18 | 34 | 10 |
| 4/5/00 | 40 | | | | | | | | 60 | 15 | 15 | | 20 | 35 | 10 |
| 4/10/00 | 40 | | | | | | | | | | | | 30 | 50 | |
| 4/12/00 | 50 | 15 | 35 | | | | | | 15 | 15 | 20 | 10 | 15 | | 40 |
| 4/19/00 | | | | | | | | | 45 | 25 | 30 | | 30 | 45 | 15 |
| 4/26/00 | 65 | | | | | | | | 35 | 35 | 45 | | 25 | 55 | 20 |
| 5/3/00 | 30 | | | | | | | | 40 | 30 | 45 | | | 45 | 25 |
| 5/11/00 | 40 | 20 | 40 | | | | | | 30 | 35 | 35 | 50 | 25 | 25 | 45 |
| 5/17/00 | 30 | | | | | | | | 35 | 30 | 25 | | 25 | 35 | 30 |
| 5/24/00 | 36 | | | | | | | | 28 | 22 | 32 | | 20 | 38 | 10 |
| 5/31/00 | 40 | | | | | | | | 45 | 35 | 30 | | 20 | 50 | 0 |
| 6/6/00 | 60 | | | | | | | | 50 | 30 | 35 | | 20 | 45 | 0 |
| 6/15/00 | 35 | 45 | 55 | | | | | | 40 | 40 | 45 | 55 | 60 | 70 | 45 |
| 6/22/00 | 40 | | | | | | | | 50 | 45 | 50 | | 25 | 50 | 0 |
| 6/28/00 | 40 | | | | | | | | 55 | 35 | 45 | | 15 | 50 | 0 |
| 7/5/00 | 45 | | | | | | | | 55 | 50 | 45 | | 20 | 65 | 0 |
| 7/13/00 | 38 | | | | | | | | 64 | 42 | 46 | | 24 | 58 | 0 |
| 7/21/00 | 30 | | | | | | | | 30 | 20 | 25 | | 25 | 35 | 0 |
| 7/24/00 | 40 | 35 | 40 | | | | | | 30 | 45 | 30 | 45 | 55 | 45 | 35 |
| 8/2/00 | 40 | | | | | | | | 40 | 45 | 45 | | 20 | 45 | 0 |
| 8/9/00 | 35 | | | 20 | | 40 | | | 45 | 45 | 35 | | 25 | 40 | 0 |
| 8/16/00 | 35 | | | 20 | 20 | 40 | 30 | | 50 | 40 | 30 | | 20 | 50 | 0 |
| 8/21/00 | 30 | 30 | 30 | 25 | 25 | 40 | 35 | | 25 | 30 | 35 | 35 | 30 | 30 | 35 |
| 8/31/00 | 25 | | | 30 | 25 | 45 | 40 | | 30 | 20 | 25 | | 25 | 30 | 20 |
| 9/6/00 | 25 | | | 30 | 25 | 30 | 30 | | 25 | 25 | 20 | | 20 | 20 | 25 |
| 9/13/00 | 25 | | | 30 | 30 | 25 | 35 | | 30 | 20 | 25 | | 20 | 30 | 25 |
| 9/19/00 | 25 | 35 | 40 | 25 | 30 | 35 | 30 | | 35 | 30 | 35 | 30 | 20 | 25 | 30 |
| 9/26/00 | 20 | | | 45 | 40 | 40 | 35 | | 35 | 25 | 35 | | 30 | 35 | 35 |
| 10/4/00 | 30 | | | 30 | 35 | 40 | 30 | | 30 | 30 | 30 | | 15 | 20 | 25 |
| 10/18/00 | - | 50 | | 40 | 35 | 50 | 50 | | 40 | 35 | 35 | | 40 | 25 | |
| 11/1/00 | | | | 55 | 45 | 50 | 45 | | 35 | 35 | 40 | | 25 | 40 | |
| 11/15/00 | - | 10 | | 25 | 30 | 20 | 35 | | 35 | 20 | 15 | | 20 | 20 | |
| 11/29/00 | | | | 45 | 40 | 55 | 55 | | 25 | 35 | - | | 20 | 30 | |
| 12/11/00 | | 25 | | 35 | 30 | 30 | 30 | | 35 | | | | | | |
| 12/15/00 | 10 | | | | | | | | | 25 | 15 | | 10 | 15 | 25 |
| 12/18/00 | | | 60 | | | | | | | | | 60 | | | |
| 1/8/01 | | | | | | | | | | | | | | | |
| 1/22/01 | | | | | | | | | | | | | | | |
| 2/5/01 | | | | | | | | | | | | | | | |
| 2/19/01 | | | | | | | | | | | | | | | |
| 3/7/01 | | | | | | | | | | | | | | | |
| 3/19/01 | | | | | | | | | | | | | | | |

PO$_4$ (mg/L) (field)

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/2/00 | | | | | | | | | | | | | 0.32 | 0.18 | |
| 3/7/00 | 0.00 | 0.00 | 0.12 | 0.00 | | | | | 0.00 | 0.00 | 0.00 | 0.00 | | | 0.00 |
| 3/23/00 | 0.00 | | | | | | | | 0.10 | 0.10 | 0.00 | 0.12 | 0.00 | 0.88 | 0.10 |
| 3/28/00 | 0.10 | | | | | | | | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4/5/00 | 0.00 | | | | | | | | 0.20 | 0.10 | 0.10 | 0.10 | 0.00 | 0.10 | 0.10 |
| 4/10/00 | 0.00 | | | | | | | | | | | | 0.10 | 0.00 | |
| 4/12/00 | 0.10 | 1.00 | 0.10 | 1.00 | | | | | 0.10 | 0.00 | 0.60 | 0.00 | 0.00 | | 0.00 |
| 4/19/00 | | | | | | | | | 0.10 | 0.10 | 0.00 | 0.10 | 0.00 | 0.00 | 0.10 |
| 4/26/00 | 0.10 | | | | | | | | 0.10 | 0.10 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 |
| 5/3/00 | 0.00 | | | | | | | | 0.10 | 0.00 | 0.00 | 0.00 | | 0.00 | 0.10 |
| 5/11/00 | 0.00 | 0.00 | 0.10 | 0.10 | | | | | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.10 |
| 5/17/00 | 0.20 | | | | | | | | 0.00 | 0.10 | 0.00 | 0.00 | 0.10 | 0.10 | 0.00 |
| 5/24/00 | 0.20 | | | | | | | | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 |
| 5/31/00 | 0.20 | | | | | | | | 0.20 | 0.10 | 0.15 | 0.15 | 0.05 | 0.10 | 0.00 |
| 6/6/00 | 0.20 | | | | | | | | 0.10 | 0.00 | 0.10 | 0.10 | 0.00 | 0.10 | 0.00 |
| 6/15/00 | 0.20 | 0.10 | 0.10 | 0.10 | | | | | 0.10 | 0.10 | 0.10 | 0.18 | 0.10 | 0.16 | 0.12 |
| 6/22/00 | 0.30 | | | | | | | | 0.10 | 0.30 | 0.20 | 0.20 | 0.00 | 0.10 | 0.00 |
| 6/28/00 | 0.20 | | | | | | | | 0.10 | 0.05 | 0.10 | 0.05 | 0.05 | 0.10 | 0.00 |
| 7/5/00 | 0.30 | | | | | | | | 0.05 | 0.10 | 0.10 | 0.10 | 0.00 | 0.10 | 0.00 |
| 7/13/00 | 0.30 | | | | | | | | 0.10 | 0.20 | 0.30 | 0.20 | 0.00 | 0.10 | 0.00 |
| 7/21/00 | 0.20 | | | | | | | | 0.10 | 0.10 | 0.20 | 0.20 | 0.10 | 0.10 | 0.10 |
| 7/24/00 | 0.18 | 0.00 | 0.08 | 0.12 | | | | | 0.10 | 0.08 | 0.10 | 0.10 | 0.10 | 0.14 | 0.12 |
| 8/2/00 | 0.20 | | | | | | | | 0.10 | 0.10 | 0.00 | 0.10 | 0.10 | 0.00 | 0.10 |
| 8/9/00 | 0.10 | | | | 0.00 | | 0.04 | | 0.12 | 0.10 | 0.04 | 0.08 | 0.00 | 0.00 | 0.00 |
| 8/16/00 | | | | | | | | | | | | | | | |
| 8/21/00 | 0.10 | 0.10 | 0.20 | 0.10 | 0.10 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.10 |
| 8/31/00 | 0.20 | | | | 0.00 | 0.10 | 0.10 | 0.00 | 0.10 | 0.10 | 0.10 | 0.10 | 0.00 | 0.10 | 0.00 |
| 9/6/00 | 0.05 | | | | 0.05 | 0.10 | 0.05 | 0.05 | 0.15 | 0.10 | 0.05 | 0.10 | 0.10 | 0.05 | 0.05 |
| 9/13/00 | 0.10 | | | | 0.10 | 0.05 | 0.05 | 0.05 | 0.10 | 0.10 | 0.05 | 0.10 | 0.10 | 0.05 | 0.05 |
| 9/19/00 | 0.05 | 0.10 | 0.20 | 0.40 | 0.10 | 0.10 | 0.10 | 0.01 | 0.10 | 0.15 | 0.05 | 0.05 | 0.50 | 0.10 | 0.05 |
| 9/26/00 | 0.00 | | | | 0.10 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.10 | 0.00 | 0.10 | 0.00 | 0.00 |
| 10/4/00 | 0.10 | | | | 0.10 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.10 | 0.10 | 0.10 | 0.00 | 0.00 |
| 10/18/00 | | 0.00 | | | 0.00 | 0.00 | 0.10 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.10 | 0.05 | |
| 11/1/00 | | | | | 0.10 | 1.60 | 0.00 | 0.00 | 0.50 | 0.00 | 0.10 | 0.10 | 0.00 | 0.00 | |
| 11/15/00 | | 0.00 | | | 0.10 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.10 | |
| 11/29/00 | | | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 0.00 | | 0.10 | 0.00 | |
| 12/11/00 | | 0.05 | | | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.02 | | | | | |
| 12/15/00 | 0.05 | | | | | | | | | | 0.10 | 0.05 | 0.00 | 0.10 | 0.05 |
| 12/18/00 | | | 15.00 | 16.60 | | | | | | | | | | | |
| 1/8/01 | | | | | | | | | | | | | | | |
| 1/22/01 | | | | | | | | | | | | | | | |
| 2/5/01 | | | | | | | | | | | | | | | |
| 2/19/01 | | | | | | | | | | | | | | | |
| 3/7/01 | | | | | | | | | | | | | | | |
| 3/19/01 | | | | | | | | | | | | | | | |

# Laboratory Data

## Ammonia-N (mg/L) (laboratory)

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar-00 | <0.01 | 0.19 | 0.15 | 0.04 | | | | | 0.11 | 0.10 | 0.06 | 0.07 | 0.02 | 0.03 | 0.3 |
| Apr-00 | <0.05 | 0.21 | 0.39 | 3.10 | | | | | 0.02 | 0.02 | 0.06 | 0.05 | <0.01 | <0.01 | 0.27 |
| May-00 | <0.01 | 0.19 | 0.17 | 0.18 | | | | | <0.01 | <0.01 | 0.16 | <0.01 | <0.01 | <0.01 | 0.26 |
| Jun-00 | <0.01 | 0.19 | 0.17 | 0.21 | | | | | <0.01 | 0.04 | 0.18 | 0.02 | <0.01 | <0.01 | 0.31 |
| Jul-00 | <0.01 | 0.20 | 0.12 | 0.11 | | | | | <0.01 | <0.01 | 0.37 | 0.10 | <0.01 | 0.01 | 0.26 |
| Aug-00 | <0.01 | 0.10 | 0.11 | 0.10 | 0.04 | 0.04 | 0.15 | 0.15 | <0.01 | <0.01 | 0.10 | <0.01 | 0.02 | 0.10 | 0.21 |
| Sep-00 | <0.01 | 0.17 | 0.44 | 0.04 | 0.17 | 0.17 | 0.23 | 0.24 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.28 |
| Oct-00 | | 0.08 | | | 0.14 | 0.13 | 0.17 | 0.18 | 0.05 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | |
| Nov-00 | | 0.07 | | | 0.14 | 0.14 | 0.22 | 0.23 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | |
| Dec-00 | 0.02 | 0.07 | 14 | 15 | 0.18 | 0.18 | 0.44 | 0.41 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.03 | 0.26 |

## $PO_4$ (mg/L) (laboratory)

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar-00 | 0.02 | 0.02 | 0.02 | 0.04 | | | | | 0.01 | 0.01 | 0.02 | 0.01 | 0.08 | 0.19 | 0.05 |
| Apr-00 | 0.04 | 0.01 | 0.13 | 0.90 | | | | | 0.04 | 0.04 | 0.02 | 0.03 | 0.06 | 0.27 | 0.05 |
| May-00 | 0.01 | 0.03 | 0.02 | 0.02 | | | | | 0.01 | 0.02 | 0.005 U | 0.01 | 0.02 | 0.03 | 0.01 |
| Jun-00 | <0.021 | <0.017 | 0.03 | 0.04 | | | | | <0.011 | <0.012 | <0.019 | <0.03 | <0.012 | <0.022 | 0.04 |
| Jul-00 | 0.019 J | 0.02 J | 0.043 J | 0.032 J | | | | | 0.01 J | 0.01 J | 0.087 J | 0.04 J | 0.023 J | 0.019 J | 0.02 J |
| Aug-00 | 0.03 | 0.05 | 0.09 | 0.04 | 0.05 | 0.05 | 0.02 | 0.02 | 0.03 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.03 |
| Sep-00 | 0.03 | 0.03 | 0.14 | 0.73 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.01 | 0.04 | 0.02 | 0.04 | 0.02 |
| Oct-00 | | 0.01 | | | 0.02 | 0.02 | 0.03 | 0.04 | 0.03 | 0.02 | 0.06 | 0.02 | 0.02 | 0.03 | |
| Nov-00 | | 0.01 | | | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | |
| Dec-00 | 0.05 | 0.01 | 14.00 | 15.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.03 |

## Chloride (mg/L) (laboratory)

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar-00 | 4.9 | 9.1 | 7.9 | 5.4 | | | | | 4.9 | 4.7 | 5.5 | 4.9 | 5.0 | 14.0 | 5.6 |
| Apr-00 | 4.8 | 7.4 | 6.8 | 6.9 | | | | | 5.8 | 5.7 | 4.6 | 4.4 | 5.0 | 13.0 | 5.4 |
| May-00 | 4.8 | 7.7 | 7.0 | 6.9 | | | | | 6.4 | 6.6 | 5.8 | 6.2 | 6.2 | 11.0 | 5.8 |
| Jun-00 | 4.5 | 7.1 | 6.5 | 6.2 | | | | | 5.8 | 6.3 | 6.1 | 6.2 | 6.0 | 8.1 | 5.6 |
| Jul-00 | 4.7 | 7.5 | 6.5 | 6.7 | | | | | 6.1 | 6.3 | 6.5 | 6.4 | 5.6 | 11.0 | 5.6 |
| Aug-00 | 5.3 | 7.6 | 7.0 | 6.7 | 7.2 | 7.2 | 7.1 | 7.1 | 6.2 | 6.5 | 6.8 | 6.4 | 6.3 | 10.0 | 5.2 |
| Sep-00 | 5 J | 8 J | 7.4 J | 7.6 J | 7.6 J | 7.6 J | 7.2 J | 7.5 J | 6.8 J | 7.2 J | 6.6 J | 6.8 J | 6.6 J | 12 J | 5.7 J |
| Oct-00 | | 7.1 | | | 7.5 | 7.5 | 7.1 | 7.2 | 6.8 | 7.3 | 6.8 | 6.7 | 6.7 | 9.6 | |
| Nov-00 | | 6.8 J | | | 7.2 J | 7.1 J | 7 J | 7.1 J | 6.7 J | 7 J | 6.7 J | 6.6 J | 6.4 J | 9.9 J | |
| Dec-00 | 4.8 | 6.9 | 9.5 | 9.6 | 7.8 | 7.4 | 8.3 | 8.1 | 6.6 | 7.1 | 7.0 | 7.1 | 6.8 | 11.0 | 5.4 |

## TOC (mg/L) (laboratory)

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar-00 | <1 | 4.7 | 1.7 | 6.2 | | | | | <1 | <1 | 4.2 | 2.2 | <1 | <1 | <1 |
| Apr-00 | <1 | <1 | <1 | 56 | | | | | <1 | <1 | 1 | <1 | <1 | <1 | <1 |
| May-00 | <1 | 1.8 | <1 | <1 | | | | | <1 | <1 | 1.6 | <1 | <1 | <1 | <1 |
| Jun-00 | <1 | <1 | <1 | <1 | | | | | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Jul-00 | <1 | <1 | <1 | <1 | | | | | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Aug-00 | <1 | <1 | <1 | 3.1 | 6.5 | 13 | 16 | 22 | 1.3 | <1 | 1.1 | <1 | <1 | <1 | 1.3 |
| Sep-00 | <1 | <1 | 5.7 | 100 | 14 | 8.9 | 7 | 8.5 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Oct-00 | | 1.1 | | | 7 | 10 | 5.5 | 6.9 | <1 | <1 | <1 | 1.1 | <1 | 1.5 | |
| Nov-00 | | <1 | | | 9.2 | 9.1 | 77 | 78 | 1 | 1.2 | 1.6 | 1 | 1.7 | 2.8 | |
| Dec-00 | 1 | 1.1 | 1,000 | 1,300 | 140 | 110 | 380 | 390 | 1 | 1.4 | <1 | <1 | 1.3 | 1.8 | <1 |

## $NO_3$ (mg/L) (laboratory)

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar-00 | 1.1 | <0.2 | <0.2 | 0.3 | | | | | 0.8 | 0.8 | <0.2 | <0.2 | 1.6 | 3.2 | <0.2 |
| Apr-00 | 1.6 | 0.2 | <0.2 | <0.2 | | | | | 1.4 | 1.4 | <0.2 | 0.4 | 1.2 | 3.4 | <0.2 |
| May-00 | 1.0 | 0.3 | 0.6 | 0.6 | | | | | 0.8 | 0.7 | 0.6 | 0.8 | 1.2 | 2.2 | <0.2 |
| Jun-00 | 1.0 | 0.8 | 0.6 | 0.5 | | | | | 0.6 | 0.5 | 0.5 | 0.6 | 0.8 | 1.2 | <0.2 |
| Jul-00 | 0.9 | 0.7 | 0.7 | 0.7 | | | | | <0.2 | 0.5 | 0.5 | 0.4 | 0.5 | 2.5 | <0.2 |
| Aug-00 | 0.9 | 0.6 | <0.2 | 0.62 | <0.2 | <0.2 | <0.2 | <0.2 | 0.41 | 0.34 | 0.48 | 0.51 | 0.5 | 1.9 | <0.2 |
| Sep-00 | 0.9 | 0.3 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | 0.21 | <0.2 | 0.29 | <0.2 | 0.3 | 2.1 | <0.2 |
| Oct-00 | | 0.2 | | | <0.2 | <0.2 | <0.2 | <0.2 | 0.22 | <0.2 | 0.31 | 0.27 | 0.3 | 1.4 | |
| Nov-00 | | 0.6 | | | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | 0.23 | 0.2 | 0.2 | 2.0 | |
| Dec-00 | 0.9 | 0.5 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | 0.2 | 2.9 | <0.2 |

## TKN (mg/L) (laboratory)

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar-00 | 0.6 J | 0.9 J | 0.6 J | 0.8 J | | | | | 0.7 J | 0.8 J | 0.5 J | <0.3 | 0.7 J | 0.8 J | 1 J |
| Apr-00 | <0.3 | 0.3 | 1.2 | 6.5 | | | | | 0.5 | <0.3 | 0.4 | 0.4 | <0.3 | 0.3 | 0.6 |
| May-00 | 0.3 | 0.6 | 0.6 | 0.6 | | | | | 0.4 | 0.6 | 0.8 | <0.3 | <0.3 | 0.7 | 0.6 |
| Jun-00 | 0.6 | 1.1 | 1.9 | 7.5 | | | | | 0.4 | 0.3 | 0.9 | 0.4 | 0.6 | 0.9 | 1.3 |
| Jul-00 | 1 | 0.8 | 1 | 1.7 | | | | | 0.4 | 0.8 | 1.3 | 0.5 | <0.5 | 1.3 | 1.1 |
| Aug-00 | 0.34 | 2.2 | 0.61 | 0.56 | 0.6 | 0.7 | 0.7 | 1 | <0.3 | <0.3 | 0.47 | <0.3 | 0.37 | 1.6 | 0.78 |
| Sep-00 | 0.3 | 1.1 | 1.5 | 2.4 | 0.9 | 0.9 | 0.9 | 0.9 | 0.5 | 0.4 | 0.7 | 0.6 | 0.5 | 0.3 | 1 |
| Oct-00 | | <0.4 | | | <0.4 | <0.5 | <0.6 | <0.8 | <0.3 | <0.4 | <0.06 | <0.6 | <0.3 | <0.5 | |
| Nov-00 | | <0.3 | | | <0.3 | <0.3 | 0.5 | 0.5 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | |
| Dec-00 | 0.5 | <0.3 | 14 | 16 | <0.3 | 0.3 | 0.8 | 0.8 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | <0.3 | 0.5 |

## Total P (mg/L) (laboratory)

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar-00 | 0.05 J | 0.08 J | 0.07 J | 0.09 J | | | | | 0.04 J | 0.04 J | 0.05 J | 0.06 J | 0.07 J | 0.06 J | 0.11 J |
| Apr-00 | 0.07 J | 0.1 J | 0.37 J | 5.4 J | | | | | 0.08 J | 0.05 J | 0.03 J | 0.06 J | 0.13 J | 0.11 J | 0.04 J |
| May-00 | 0.1 J | 0.18 J | 0.16 J | 0.04 J | | | | | 0.03 J | 0.04 J | 0.03 J | 0.06 J | 0.1 J | 0.06 J | 0.02 J |
| Jun-00 | 0.04 | 0.12 | 0.08 | 0.11 | | | | | 0.06 | 0.04 | 0.11 | 0.03 | 0.15 | 0.09 | 0.09 |
| Jul-00 | 0.19 J | 0.12 J | 0.25 J | 0.25 J | | | | | 0.16 J | 0.15 J | 0.1 J | 0.19 J | 0.14 J | 0.1 J | 0.05 J |
| Aug-00 | 0.099 | 0.4 | 0.095 | 0.13 | 0.053 | 0.054 | 0.041 | 0.18 | 0.21 | 0.053 | 0.063 | 0.086 | 0.057 | 0.09 | 0.059 |
| Sep-00 | 0.06 J | 0.27 J | 0.2 J | 0.86 J | 0.031 J | 0.028 J | 0.032 J | 0.075 J | 0.074 J | 0.1 J | 0.047 J | 0.23 J | 0.049 J | 0.06 J | 0.036 J |
| Oct-00 | | 0.025 | | | 0.034 | 0.046 | 0.13 | 0.077 | 0.039 | 0.13 | 0.18 | 0.21 | 0.029 | 0.11 | |
| Nov-00 | | 0.21 J | | | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | |
| Dec-00 | 0.04 | <0.02 | 16 | <2 | 0.03 | 0.02 | 0.08 | 0.11 | 0.1 | 4 | 0.3 | 0.1 | 0.03 | 0.02 | 0.08 |

HPC (CFU/mL) (laboratory)

| Date | 3LF | 57LF | 60LF | 61LF | 62LFA | 62LFB | 63LFA | 63LFB | 58LFA | 58LFB | 59LFA | 59LFB | 4LF | 4UF | 21LF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar-00 | 9.8E+02 | 2.4E+05 | 1.6E+05 | 5.4E+04 | | | | | 1.5E+04 | 2.1E+04 | 1.5E+05 | 1.2E+05 | | | 1.9E+04 |
| Apr-00 | 6.0E+03 | 1.4E+05 | 2.5E+06 | 1.7E+06 | | | | | 6.1E+03 | 5.9E+03 | 3.2E+05 | 1.7E+05 | 1.3E+04 | 1.5E+04 | 3.5E+02 |
| May-00 | 7.4E+03 | 1.4E+06 | 1.0E+05 | 6.1E+04 | | | | | 1.4E+04 | 8.5E+02 | 1.4E+05 | 2.0E+04 | 1.4E+03 | 9.2E+02 | 2.8E+02 |
| Jun-00 | 1.3E+03 | 1.7E+05 | 8.4E+04 | 4.0E+05 | | | | | 1.5E+03 | 5.2E+02 | 2.1E+04 | 9.2E+03 | 7.4E+03 | 6.4E+03 | 4.3E+02 |
| Jul-00 | 4.3E+03 | 3.1E+04 | 1.5E+04 | 8.1E+04 | | | | | 1.1E+04 | 6.0E+02 | 5.2E+03 | 2.9E+03 | 2.5E+04 | 3.4E+03 | 2.5E+02 |
| Aug-00 | 1.6E+03 | 1.2E+05 | 1.2E+05 | 9.6E+04 | 8.8E+03 | 5.6E+03 | 2.3E+04 | 1.8E+04 | 2.9E+03 | 7.0E+02 | 3.7E+04 | 1.1E+03 | 5.4E+03 | 7.8E+03 | 2.6E+04 |
| Sep-00 | 1.1E+04 | 5.8E+04 | 7.9E+04 | 8.1E+06 | 3.1E+03 | 6.8E+03 | 4.1E+03 | 1.3E+03 | 2.1E+04 | 3.1E+02 | 1.9E+04 | 3.2E+03 | 4.1E+04 | 3.1E+04 | 1.9E+04 |
| Oct-00 | | 2.6E+03 | | | 6.9E+02 | 6.0E+02 | 2.0E+03 | 1.0E+02 | 1.5E+03 | 5.9E+03 | 8.1E+04 | 2.8E+02 | 4.4E+03 | 2.7E+03 | |
| Nov-00 | | 2.2E+03 | | | 5.7E+02 | 1.5E+02 | 1.6E+03 | 5.2E+02 | 1.8E+03 | 1.0E+02 | 2.4E+04 | 1.4E+04 | 3.6E+03 | 1.1E+03 | |
| Dec-00 | 3.6E+02 | 1.2E+03 | 2.8E+05 | 8.2E+05 | 1.7E+03 | 1.3E+03 | 1.1E+03 | 4.0E+02 | 5.5E+03 | 1.9E+02 | 3.2E+04 | 1.6E+03 | 8.5E+03 | 1.8E+03 | 5.3E+03 |
| *Mean* | 4.1E+03 | 2.2E+05 | 4.2E+05 | 1.4E+06 | 3.0E+03 | 2.9E+03 | 6.4E+03 | 4.1E+03 | 8.0E+03 | 3.6E+03 | 8.3E+04 | 3.4E+04 | 1.2E+04 | 7.8E+03 | 8.8E+03 |

# APPENDIX E
# GROUNDWATER ELEVATIONS

| Groundwater Elevations | | | | |
|---|---|---|---|---|
| Well | TOC Elev (msl) | Date | DTW (ft) | Elev (msl) |
| 007G03LF | 283.32 | 3/7/00 | 29.40 | 253.92 |
| | | 3/14/00 | 29.44 | 253.88 |
| | | 3/23/00 | 29.09 | 254.23 |
| | | 4/10/00 | 28.87 | 254.45 |
| | | 5/11/00 | 28.40 | 254.92 |
| | | 6/15/00 | 28.40 | 254.92 |
| | | 7/16/00 | 28.90 | 254.42 |
| | | 8/21/00 | 29.85 | 253.47 |
| | | 9/19/00 | 30.44 | 252.88 |
| | | 10/18/00 | 30.94 | 252.38 |
| | | 11/15/00 | 31.17 | 252.15 |
| | | 12/12/00 | 31.18 | 252.14 |
| 007G04LF | 283.12 | 3/7/00 | 29.47 | 253.65 |
| | | 3/14/00 | 29.58 | 253.54 |
| | | 3/23/00 | 29.53 | 253.59 |
| | | 4/10/00 | 28.82 | 254.3 |
| | | 5/11/00 | 28.71 | 254.41 |
| | | 6/15/00 | 28.91 | 254.21 |
| | | 7/16/00 | 29.09 | 254.03 |
| | | 8/21/00 | 30.14 | 252.98 |
| | | 9/19/00 | 30.82 | 252.3 |
| | | 10/18/00 | 31.17 | 251.95 |
| | | 11/15/00 | 31.45 | 251.67 |
| | | 12/12/00 | 31.51 | 251.61 |
| 007G04UF | 283.21 | 3/7/00 | 29.51 | 253.7 |
| | | 3/14/00 | 29.71 | 253.5 |
| | | 3/23/00 | 29.54 | 253.67 |
| | | 4/10/00 | 28.91 | 254.3 |
| | | 5/11/00 | 28.72 | 254.49 |
| | | 6/15/00 | 28.66 | 254.55 |
| | | 7/16/00 | 29.17 | 254.04 |
| | | 8/21/00 | 30.15 | 253.06 |
| | | 9/19/00 | 30.83 | 252.38 |
| | | 10/18/00 | 31.26 | 251.95 |
| | | 11/15/00 | 31.49 | 251.72 |
| | | 12/12/00 | 31.59 | 251.62 |
| 007G21LF | 283.66 | 3/7/00 | 32.6 | 251.06 |
| | | 3/14/00 | 32.82 | 250.84 |
| | | 3/23/00 | 32.75 | 250.91 |
| | | 4/10/00 | 32.41 | 251.25 |
| | | 5/11/00 | 32.22 | 251.44 |
| | | 6/15/00 | 32.31 | 251.35 |
| | | 7/16/00 | 32.82 | 250.84 |
| | | 8/21/00 | 33.55 | 250.11 |
| | | 9/19/00 | 34.1 | 249.56 |
| | | 10/18/00 | | |
| | | 11/15/00 | | |
| | | 12/12/00 | 34.73 | 248.93 |

| Groundwater Elevations | | | | |
|---|---|---|---|---|
| **Well** | **TOC Elev (msl)** | **Date** | **DTW (ft)** | **Elev (msl)** |
| 007G57LF | 281.71 | 3/7/00 | 28.21 | 253.5 |
| | | 3/14/00 | 28.27 | 253.44 |
| | | 3/23/00 | | |
| | | 4/10/00 | 27.65 | 254.06 |
| | | 5/11/00 | 27.3 | 254.41 |
| | | 6/15/00 | 27.54 | 254.17 |
| | | 7/16/00 | 27.81 | 253.9 |
| | | 8/21/00 | 28.76 | 252.95 |
| | | 9/19/00 | 29.44 | 252.27 |
| | | 10/18/00 | | |
| | | 11/15/00 | | |
| | | 12/12/00 | | |
| 007G58LF | 283.21 | 3/7/00 | 29.61 | 253.6 |
| | | 3/14/00 | 29.61 | 253.6 |
| | | 3/23/00 | 29.4 | 253.81 |
| | | 4/10/00 | 29.02 | 254.19 |
| | | 5/11/00 | 28.55 | 254.66 |
| | | 6/15/00 | 28.87 | 254.34 |
| | | 7/16/00 | 29.2 | 254.01 |
| | | 8/21/00 | 30.1 | 253.11 |
| | | 9/19/00 | 30.82 | 252.39 |
| | | 10/18/00 | 31.21 | 252.0 |
| | | 11/15/00 | 31.79 | 251.42 |
| | | 12/12/00 | 31.63 | 251.58 |
| 007G59LF | 283.19 | 3/7/00 | 29.57 | 253.62 |
| | | 3/14/00 | 29.47 | 253.72 |
| | | 3/23/00 | 29.22 | 253.97 |
| | | 4/10/00 | 28.86 | 254.33 |
| | | 5/11/00 | 28.6 | 254.59 |
| | | 6/15/00 | 28.72 | 254.47 |
| | | 7/16/00 | 29.35 | 253.84 |
| | | 8/21/00 | 30.01 | 253.18 |
| | | 9/19/00 | 30.68 | 252.51 |
| | | 10/18/00 | 31.14 | 252.05 |
| | | 11/15/00 | 31.48 | 251.71 |
| | | 12/12/00 | 31.44 | 251.75 |
| 007G60LF | 282.42 | 3/7/00 | 28.86 | 253.56 |
| | | 3/14/00 | 28.53 | 253.89 |
| | | 3/23/00 | | |
| | | 4/10/00 | 28.2 | 254.22 |
| | | 5/11/00 | 27.92 | 254.5 |
| | | 6/15/00 | 27.72 | 254.7 |
| | | 7/16/00 | 28.4 | 254.02 |
| | | 8/21/00 | 27.05 | 255.37 |
| | | 9/19/00 | 30 | 252.42 |
| | | 10/18/00 | | |
| | | 11/15/00 | | |
| | | 12/12/00 | 30.5 | 251.92 |
| 007G61LF | 282.55 | 3/7/00 | 28.89 | 253.66 |
| | | 3/14/00 | 28.62 | 253.93 |
| | | 3/23/00 | | |
| | | 4/10/00 | 28.4 | 254.15 |
| | | 5/11/00 | 27.97 | 254.58 |
| | | 6/15/00 | 27.95 | 254.60 |
| | | 7/16/00 | 28.46 | 254.09 |
| | | 8/21/00 | 29.45 | 253.10 |
| | | 9/19/00 | 30.12 | 252.43 |
| | | 10/18/00 | | |
| | | 11/15/00 | | |
| | | 12/12/00 | 30.5 | 252.05 |

| Groundwater Elevations | | | | |
|---|---|---|---|---|
| **Well** | **TOC Elev (msl)** | **Date** | **DTW (ft)** | **Elev (msl)** |
| 007G62LF | 283.37 | 8/21/00 | 30.05 | |
| | | 9/19/00 | 30.58 | |
| | | 10/18/00 | 31.08 | |
| | | 11/15/00 | 31.44 | |
| | | 12/12/00 | 31.46 | |
| 007G63LF | 283.40 | 8/21/00 | 29.88 | |
| | | 9/19/00 | 30.4 | |
| | | 10/18/00 | 30.92 | |
| | | 11/15/00 | 31.38 | |
| | | 12/12/00 | 31.3 | |

***Notes:***

TOC = Top of (well) casing
DTW = Depth to water
msl = Mean sea level
* = Depth to water measurement not taken synoptically with other wells

# APPENDIX F

# HYDRAULIC EVALUATION

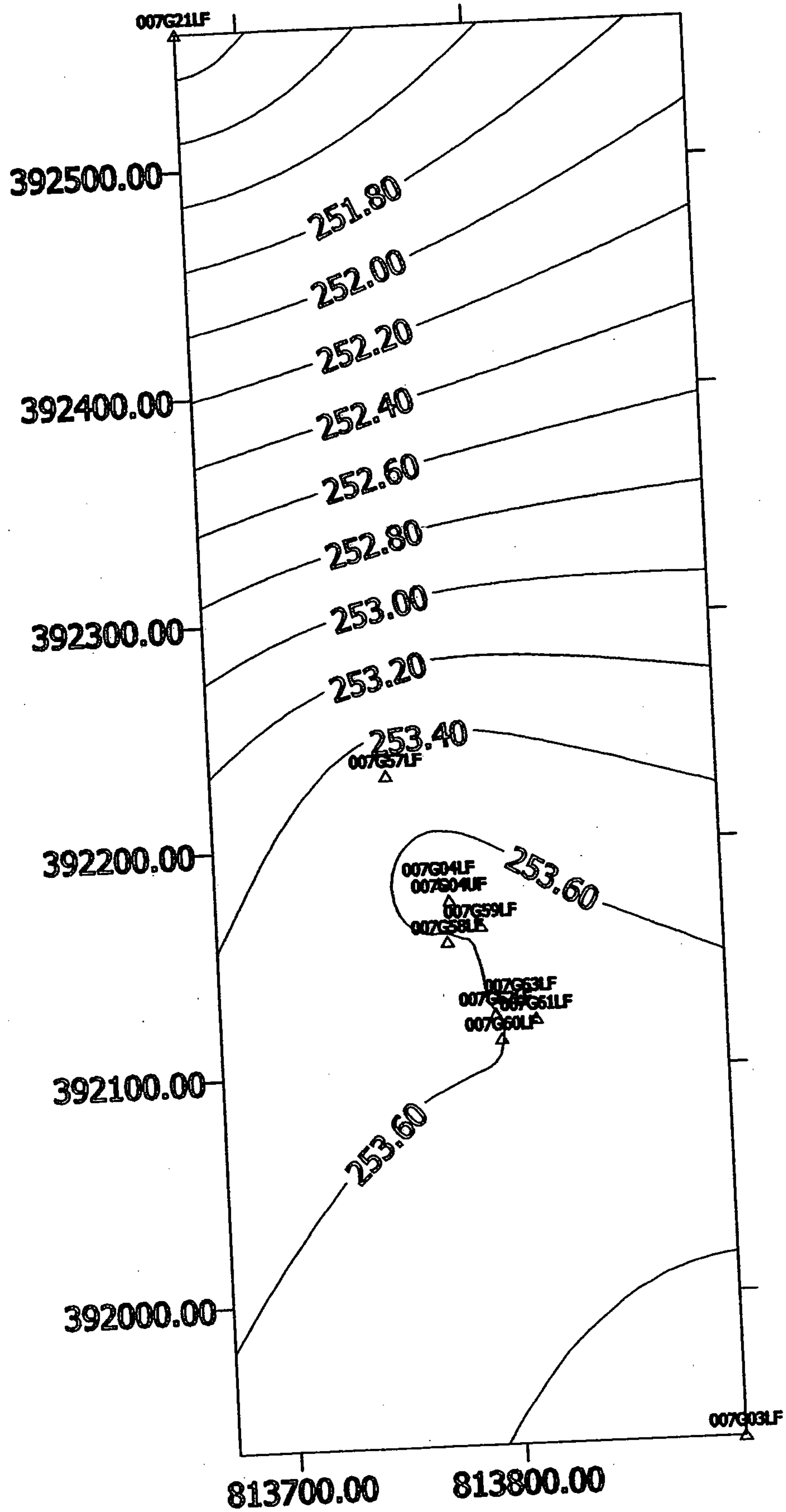



FIGURE 1
POTENTIOMETRIC SURFACE 3-8-00 (baseline)

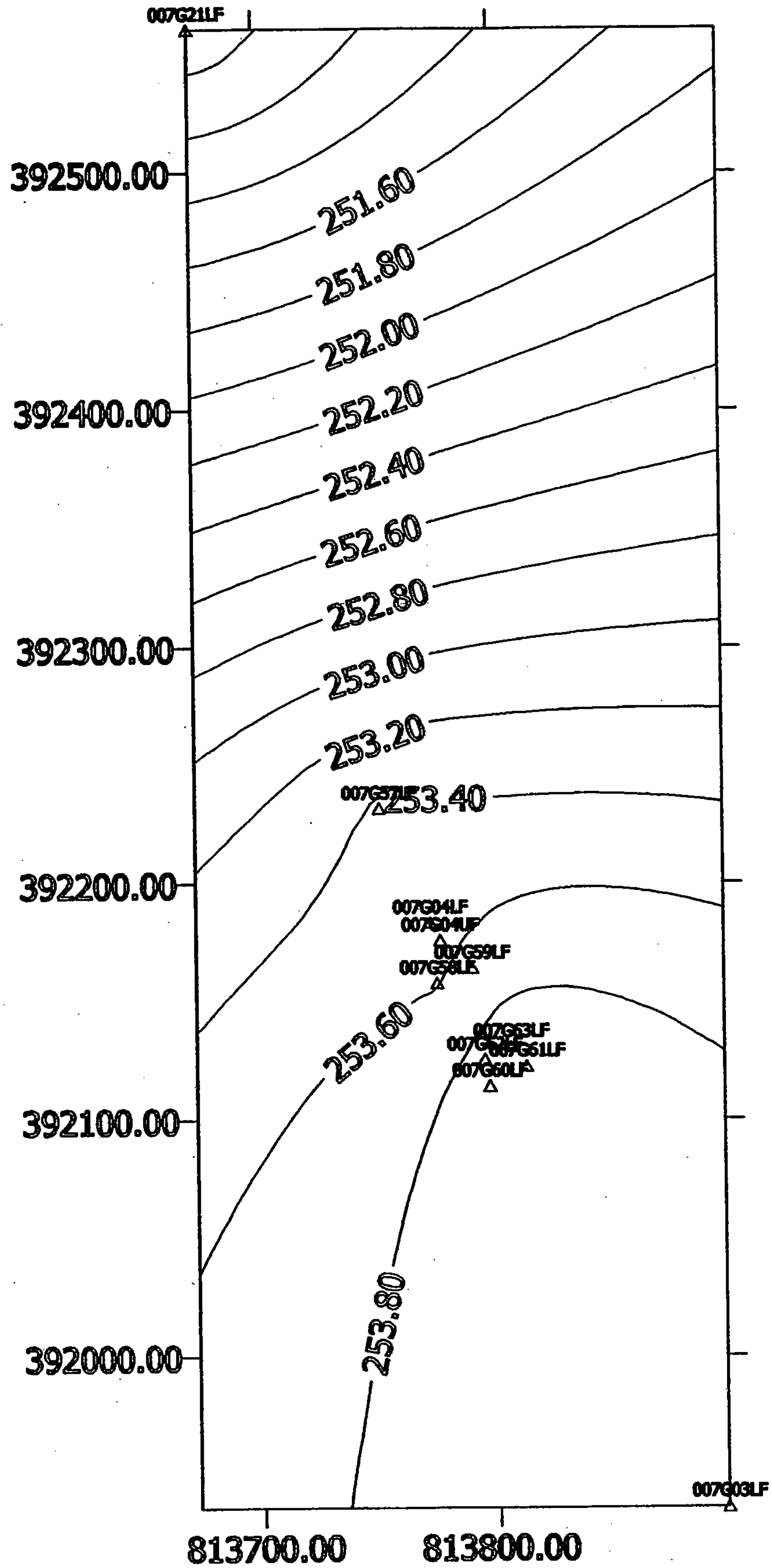



FIGURE 2
POTENTIOMETRIC SURFACE 3-14-00

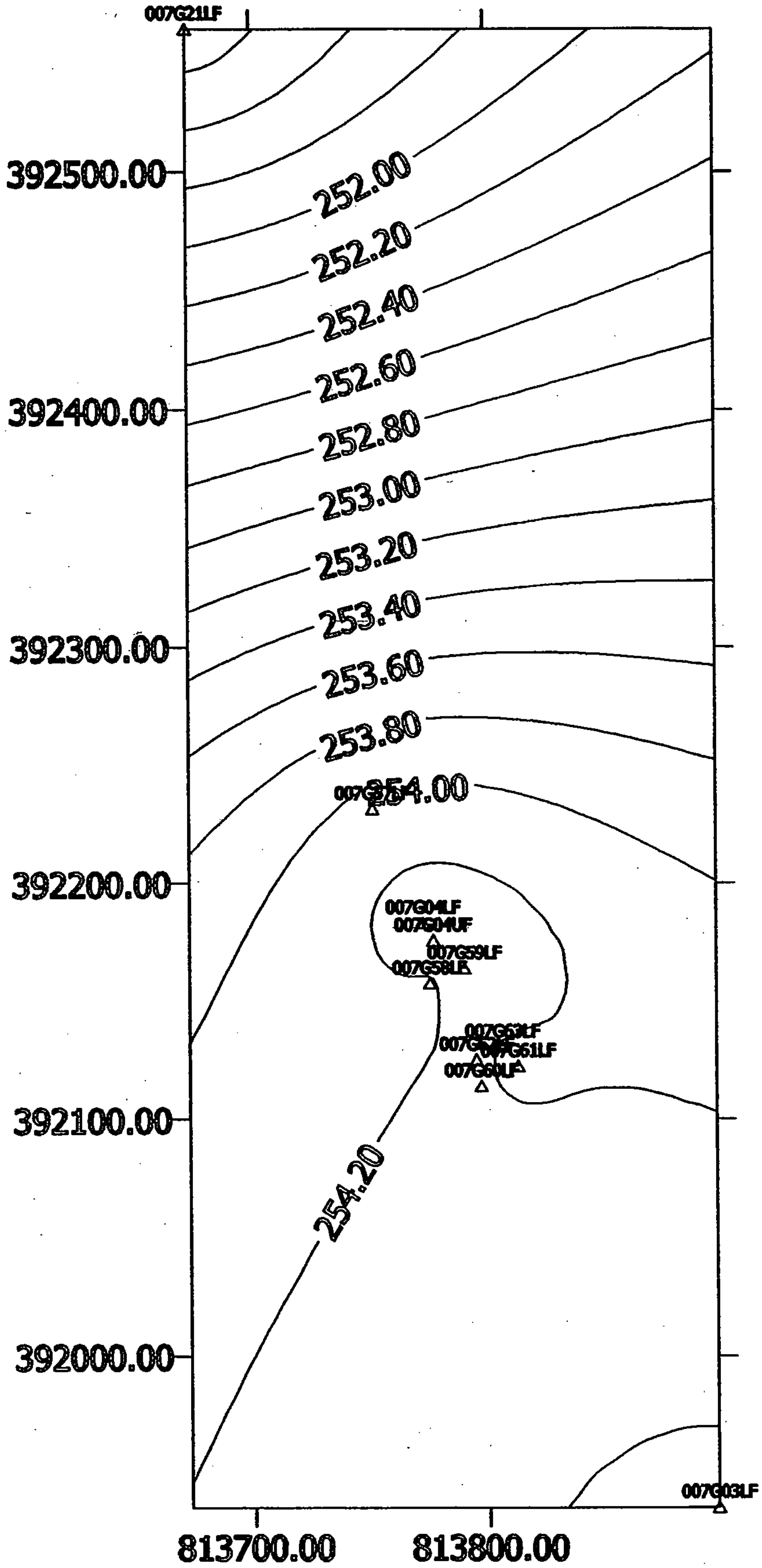



FIGURE 3
POTENTIOMETRIC SURFACE 4-10-00

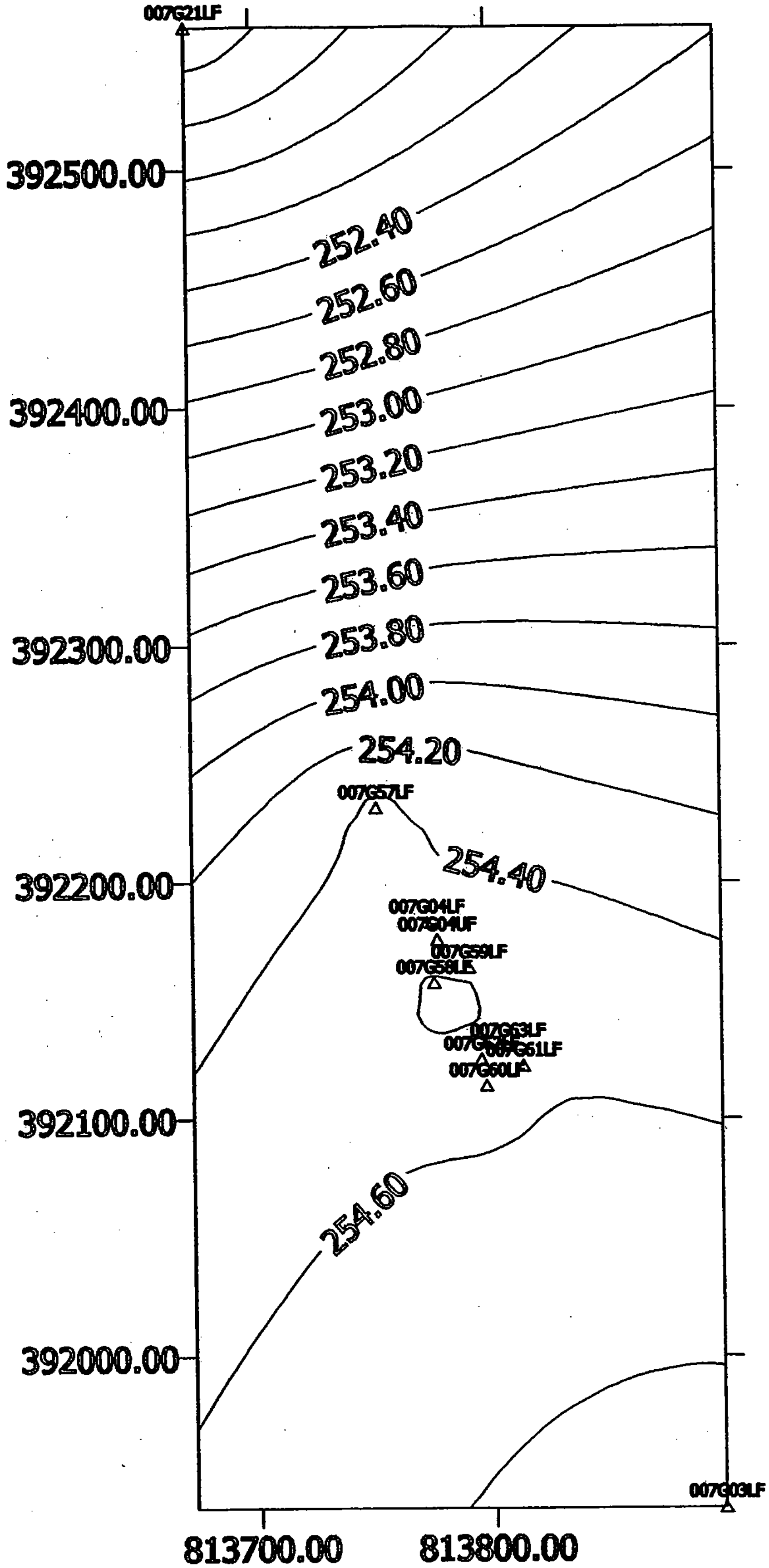



FIGURE 4
POTENTIOMETRIC SURFACE 5-11-00

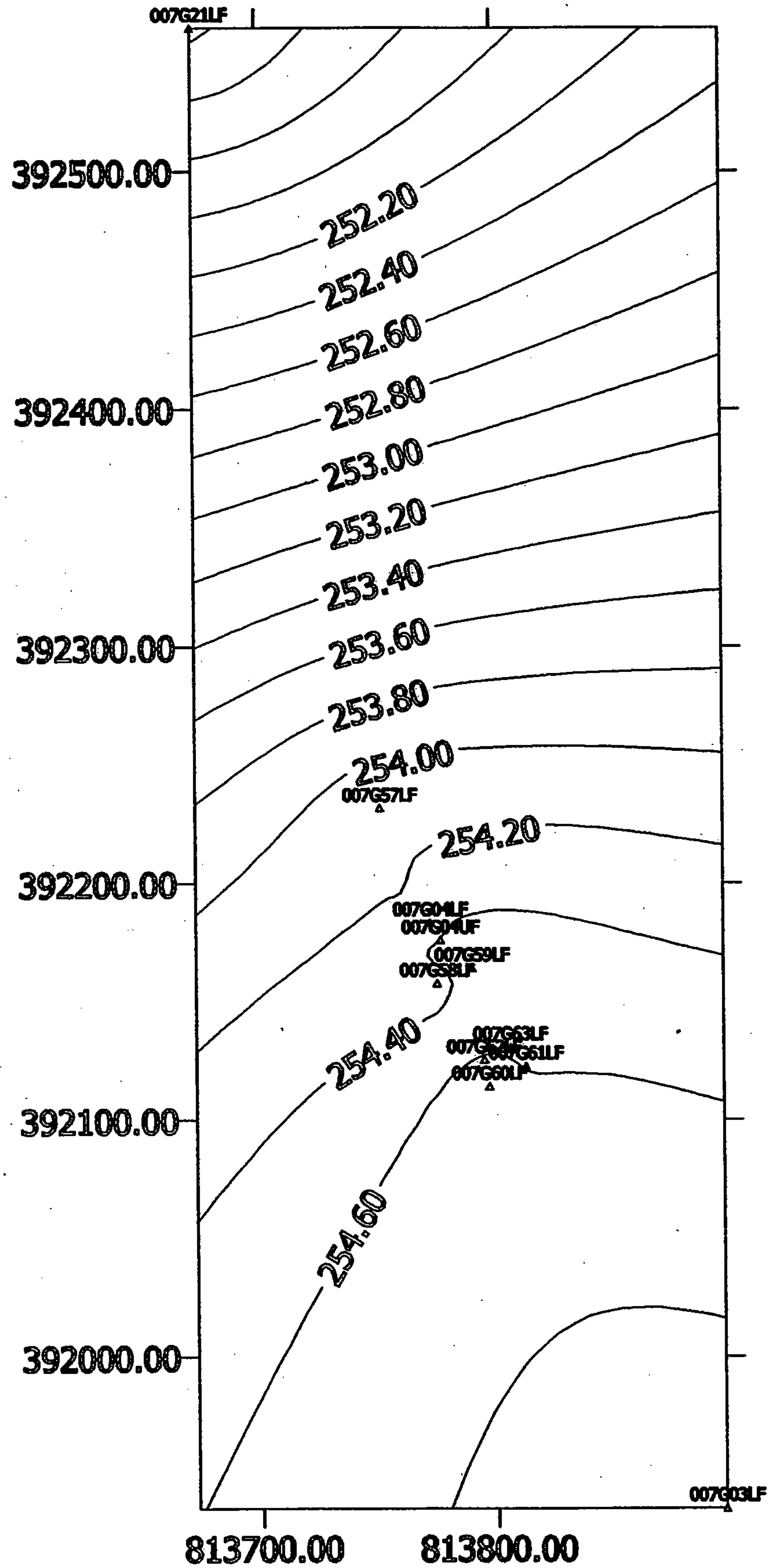



FIGURE 5
POTENTIOMETRIC SURFACE 6-15-00

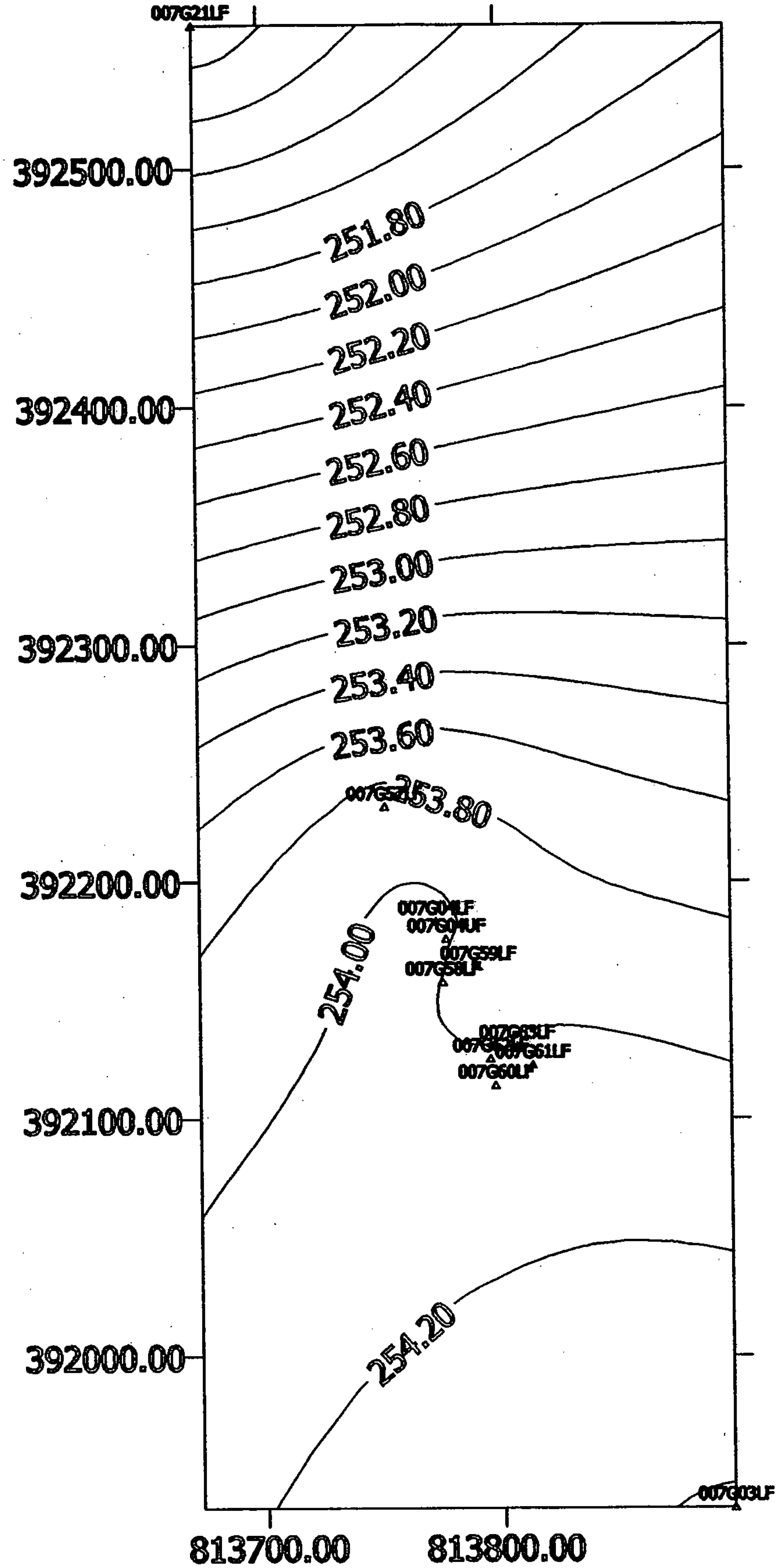



FIGURE 6
POTENTIOMETRIC SURFACE 7-16-00

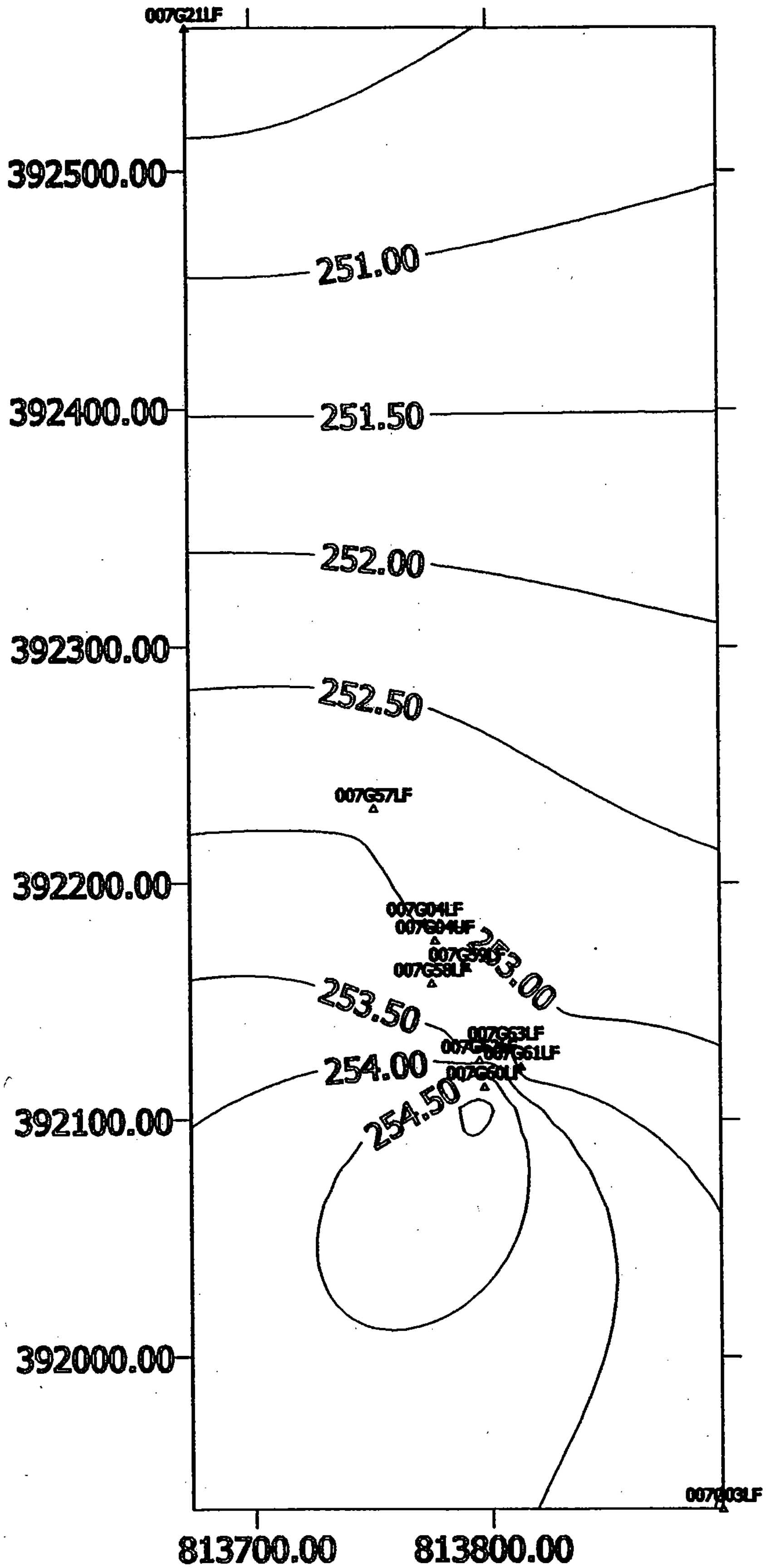



FIGURE 7
POTENTIOMETRIC SURFACE 8-21-00

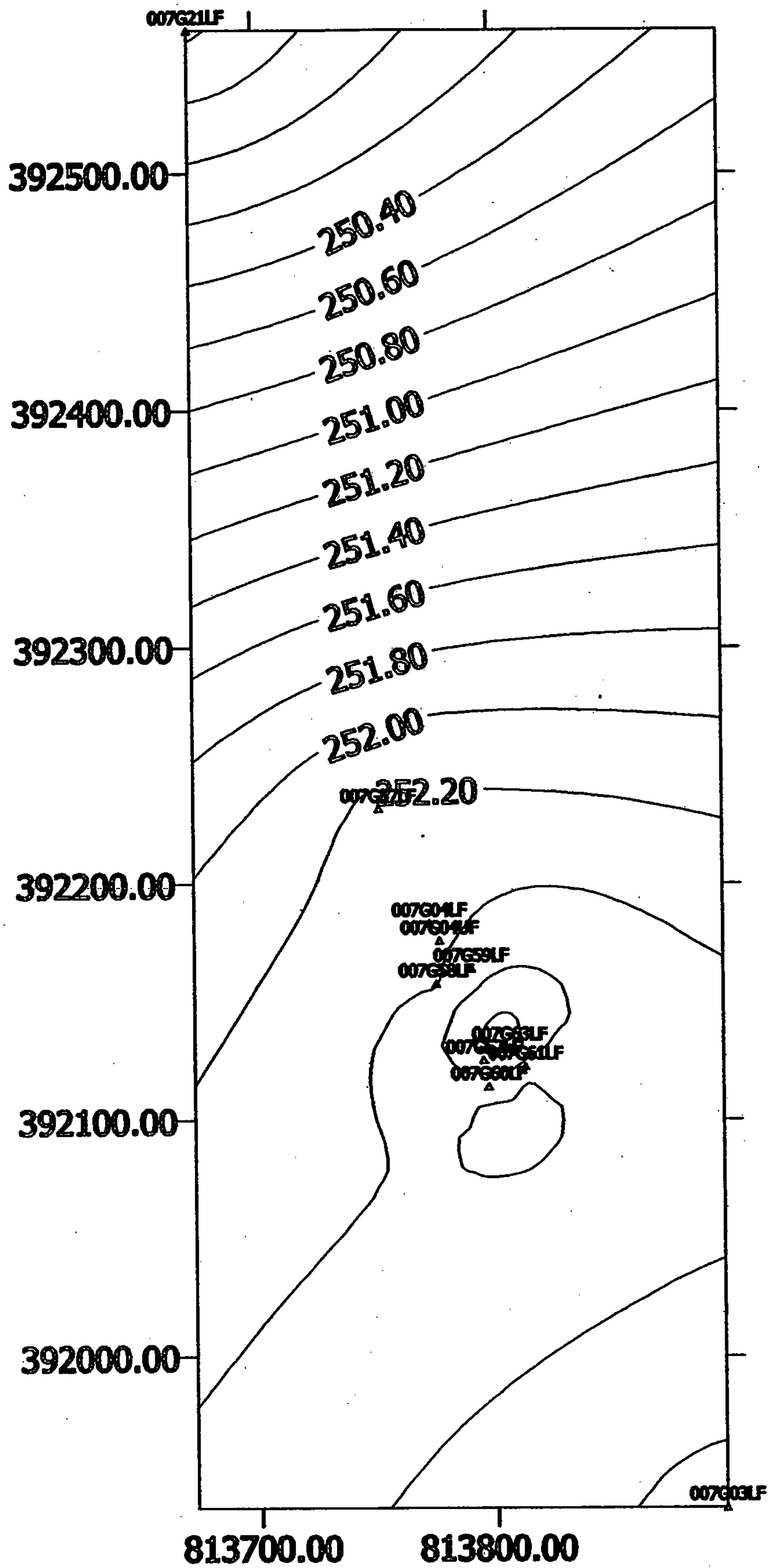



FIGURE 8
POTENTIOMETRIC SURFACE 9-19-00

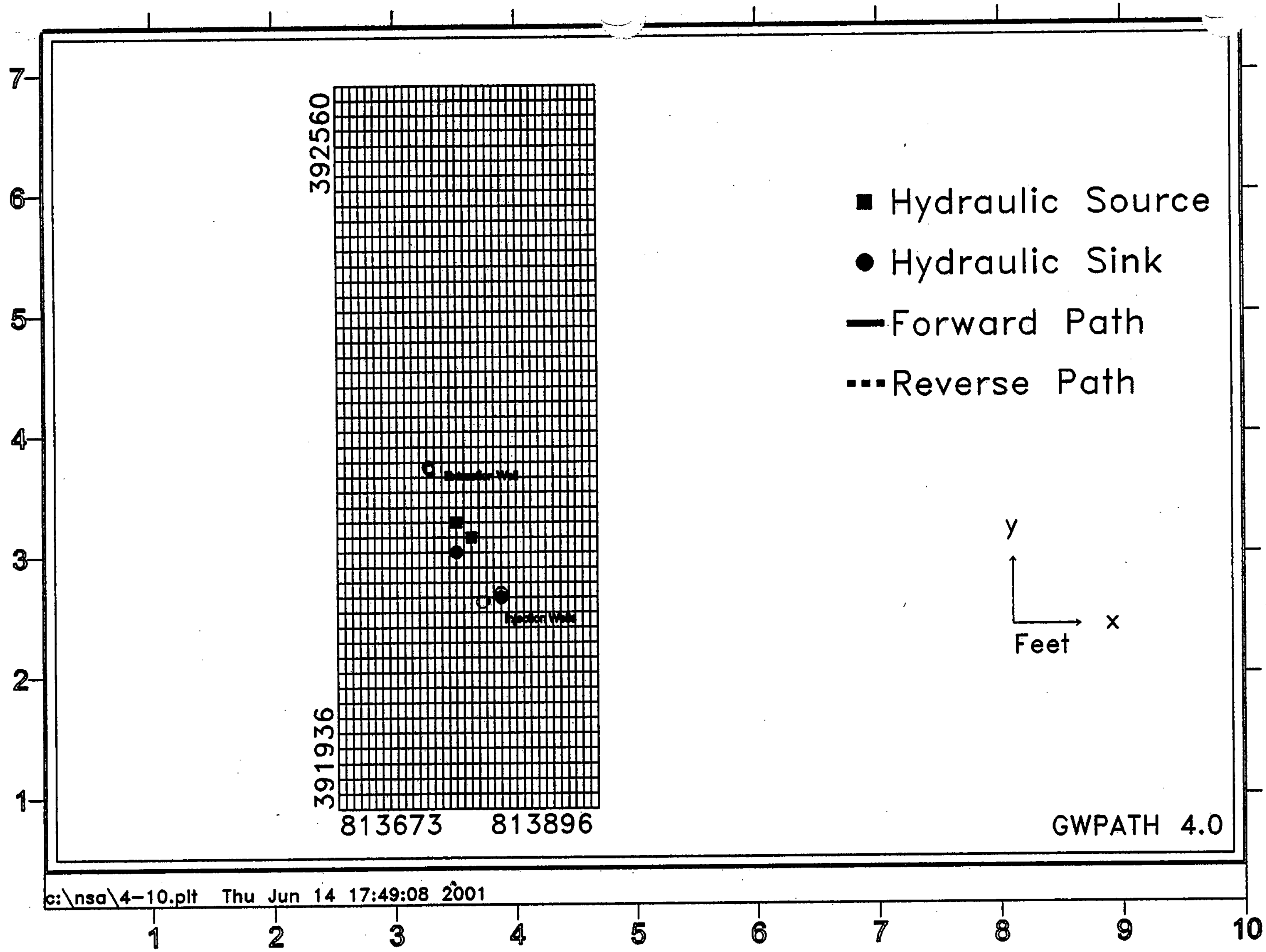



FIGURE 9
4-10-00 (~30 DAYS TRAVEL TIME)

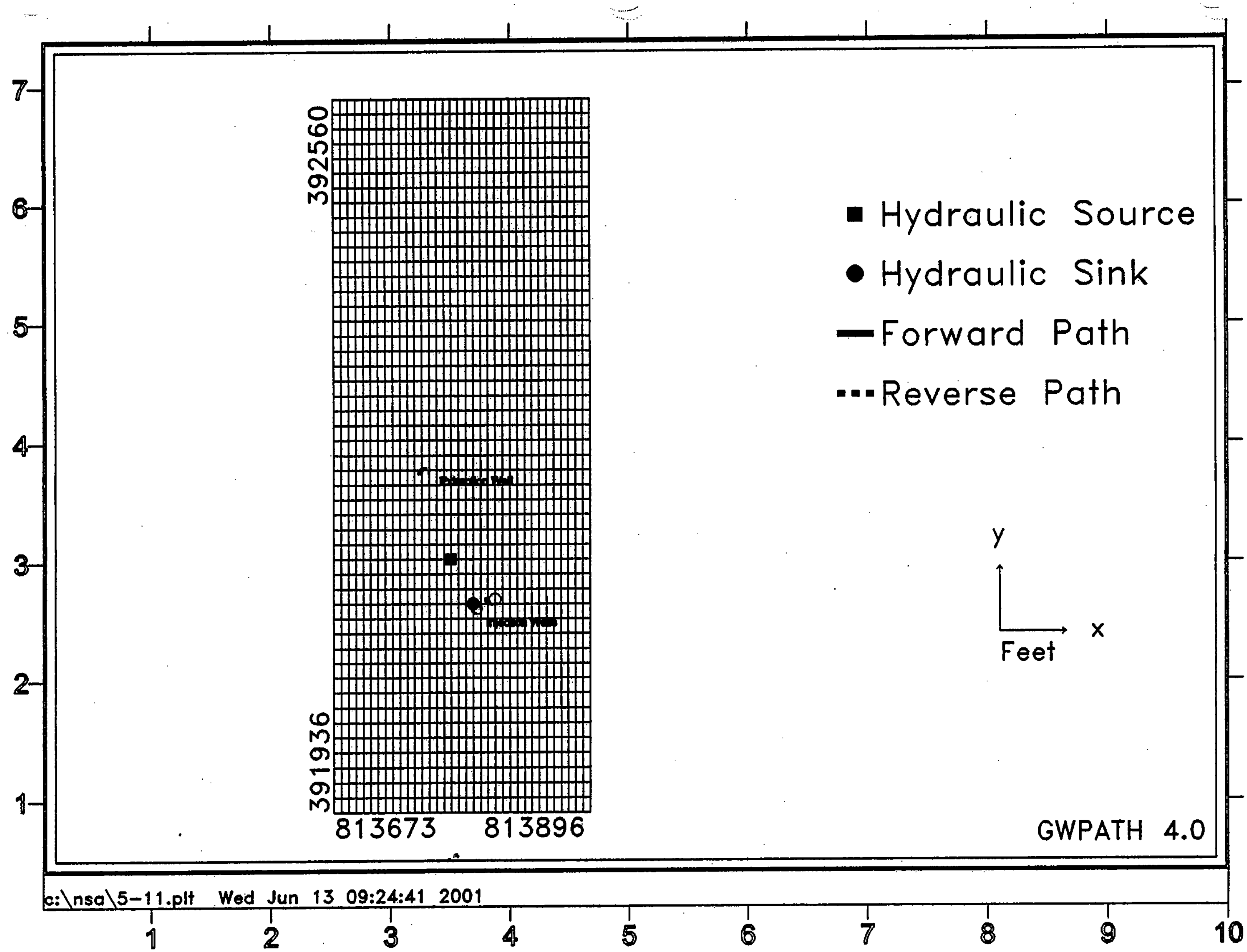



FIGURE 10
5-11-00 (~60 DAYS TRAVEL TIME)

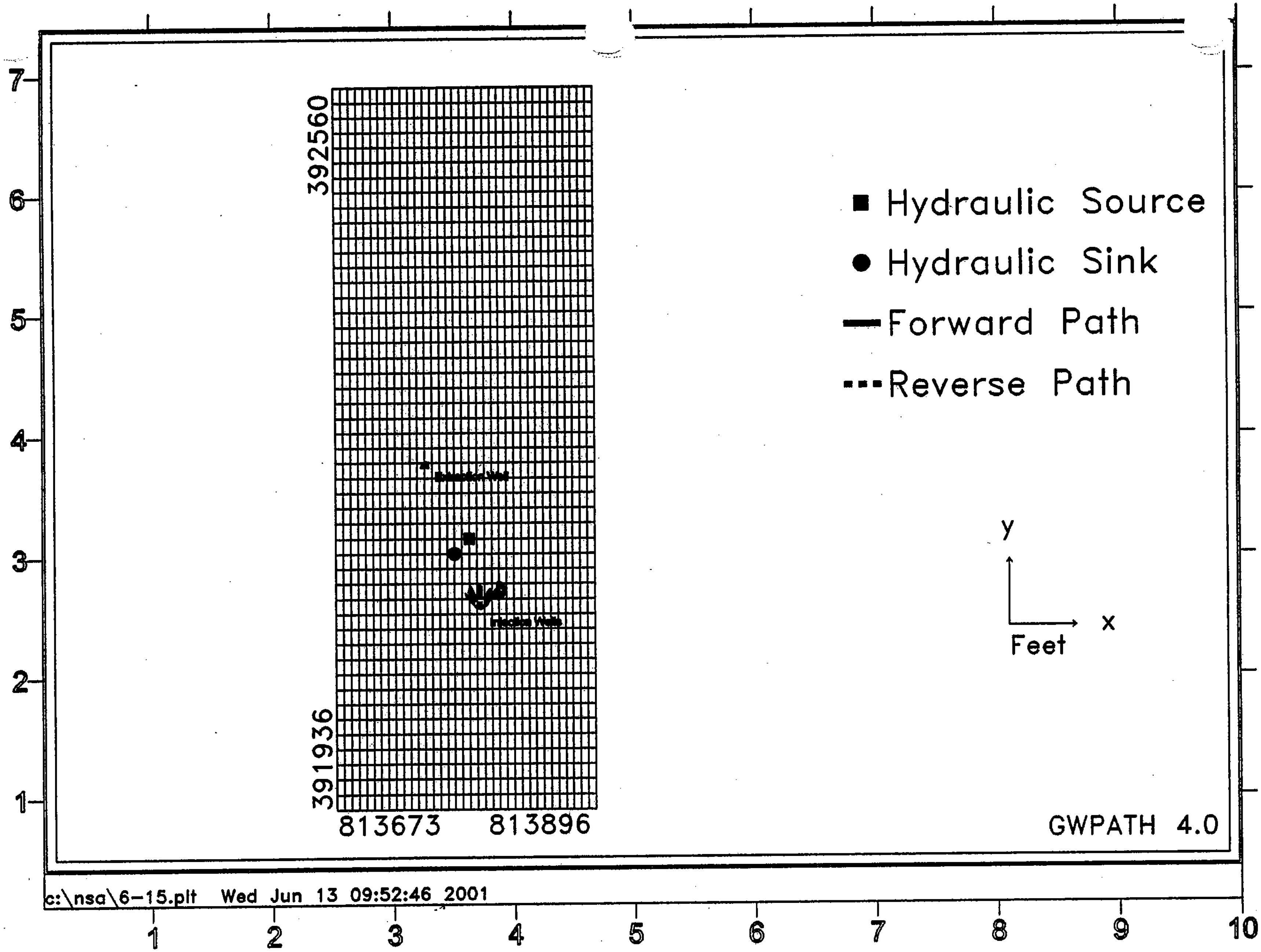



FIGURE 11
6-15-00 (~90 DAYS TRAVEL TIME)

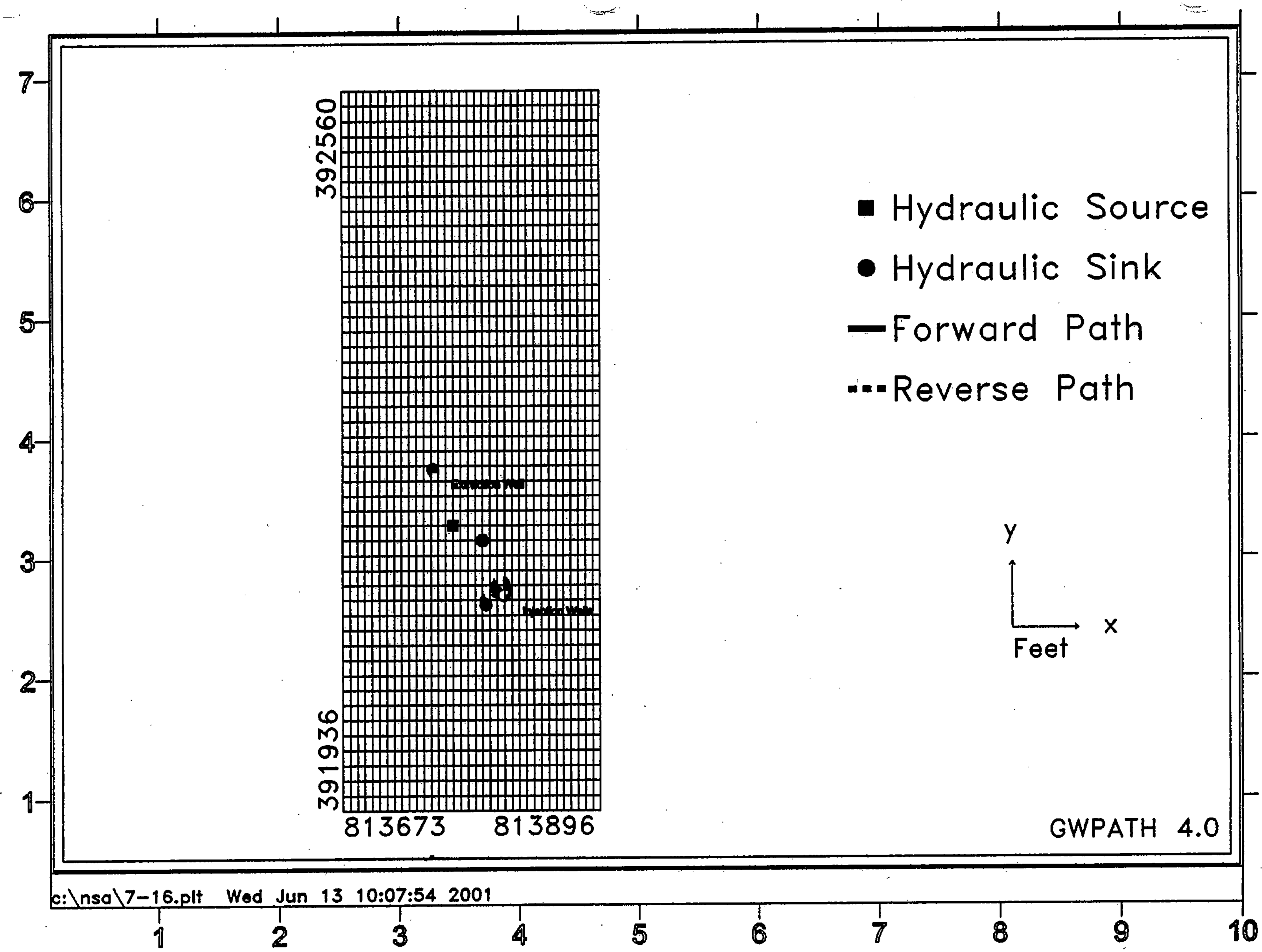



FIGURE 12
7-16-00 (~120 DAYS TRAVEL TIME)

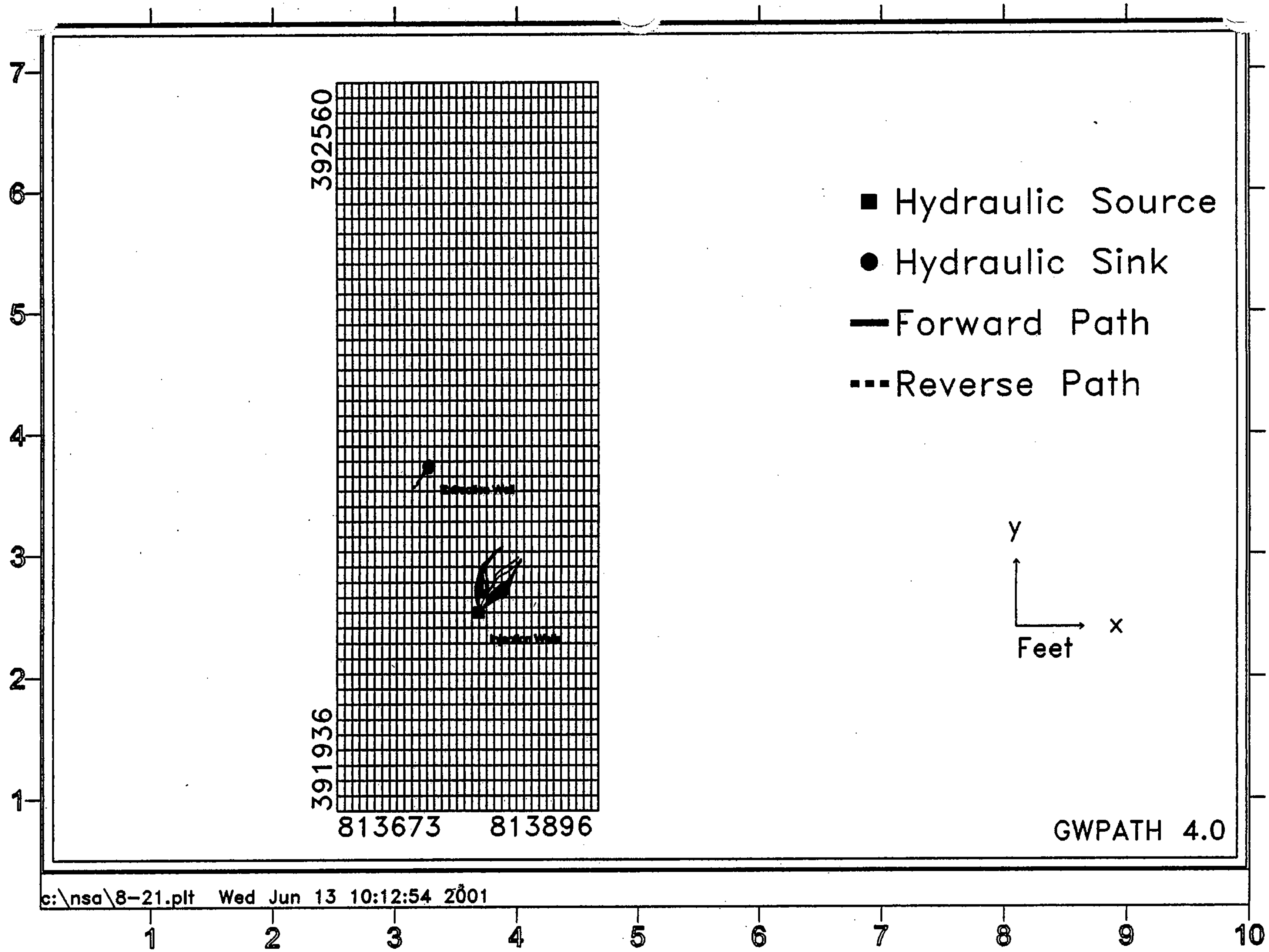



FIGURE 13
8-21-00 (~160 DAYS TRAVEL TIME)

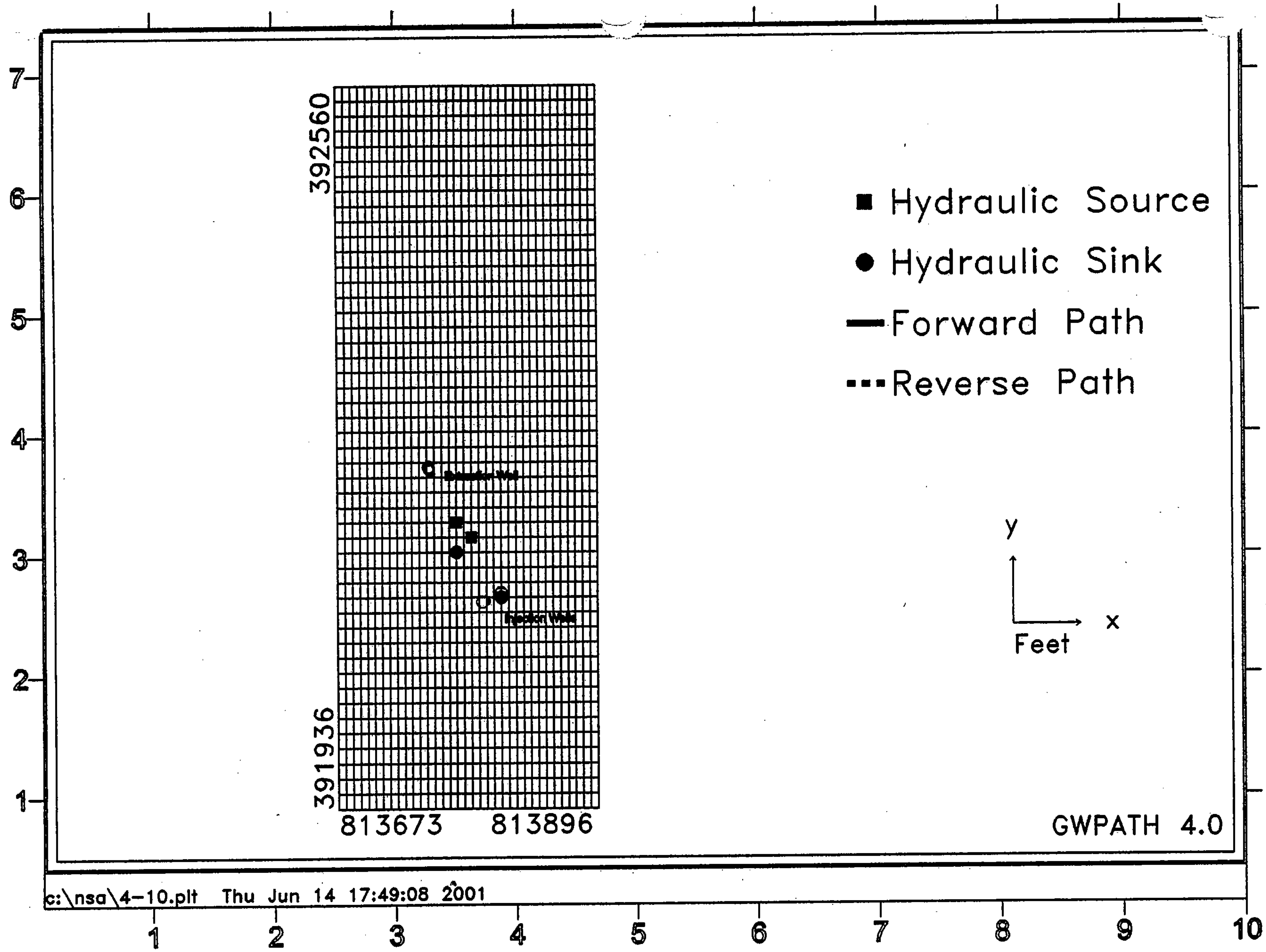



FIGURE 9
4-10-00 (~30 DAYS TRAVEL TIME)

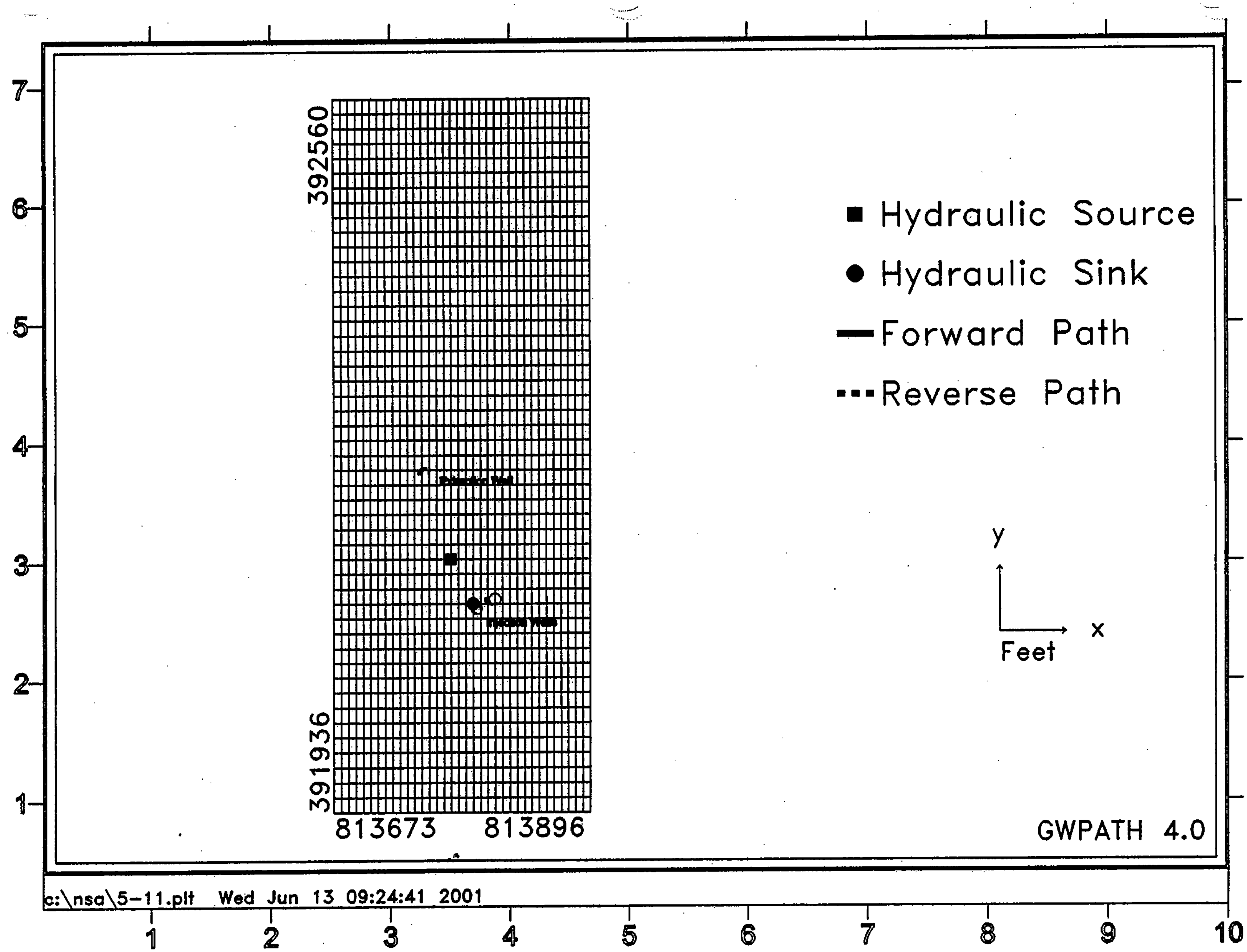



FIGURE 10
5-11-00 (~60 DAYS TRAVEL TIME)

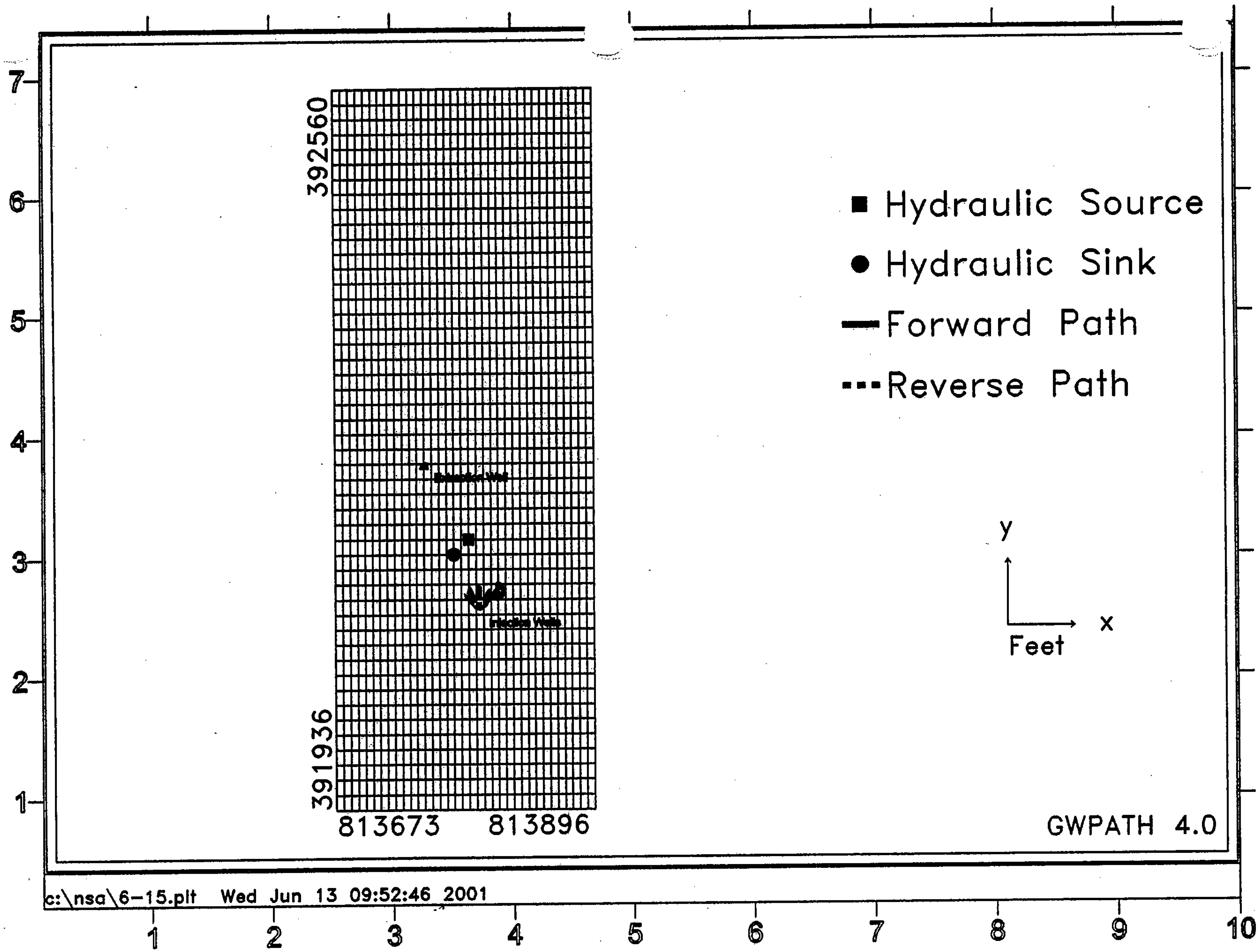



FIGURE 11
6-15-00 (~90 DAYS TRAVEL TIME)

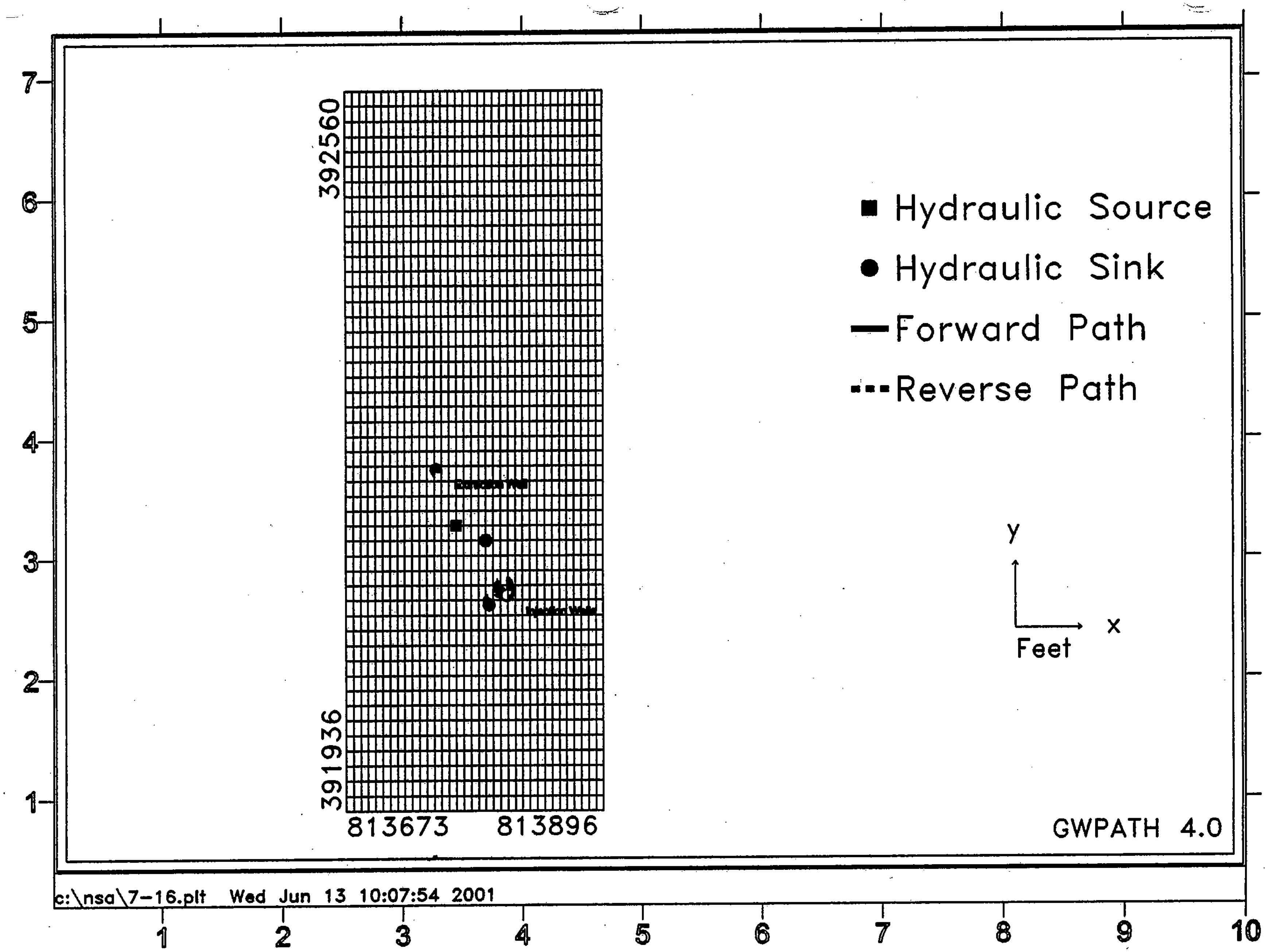



FIGURE 12
7-16-00 (~120 DAYS TRAVEL TIME)

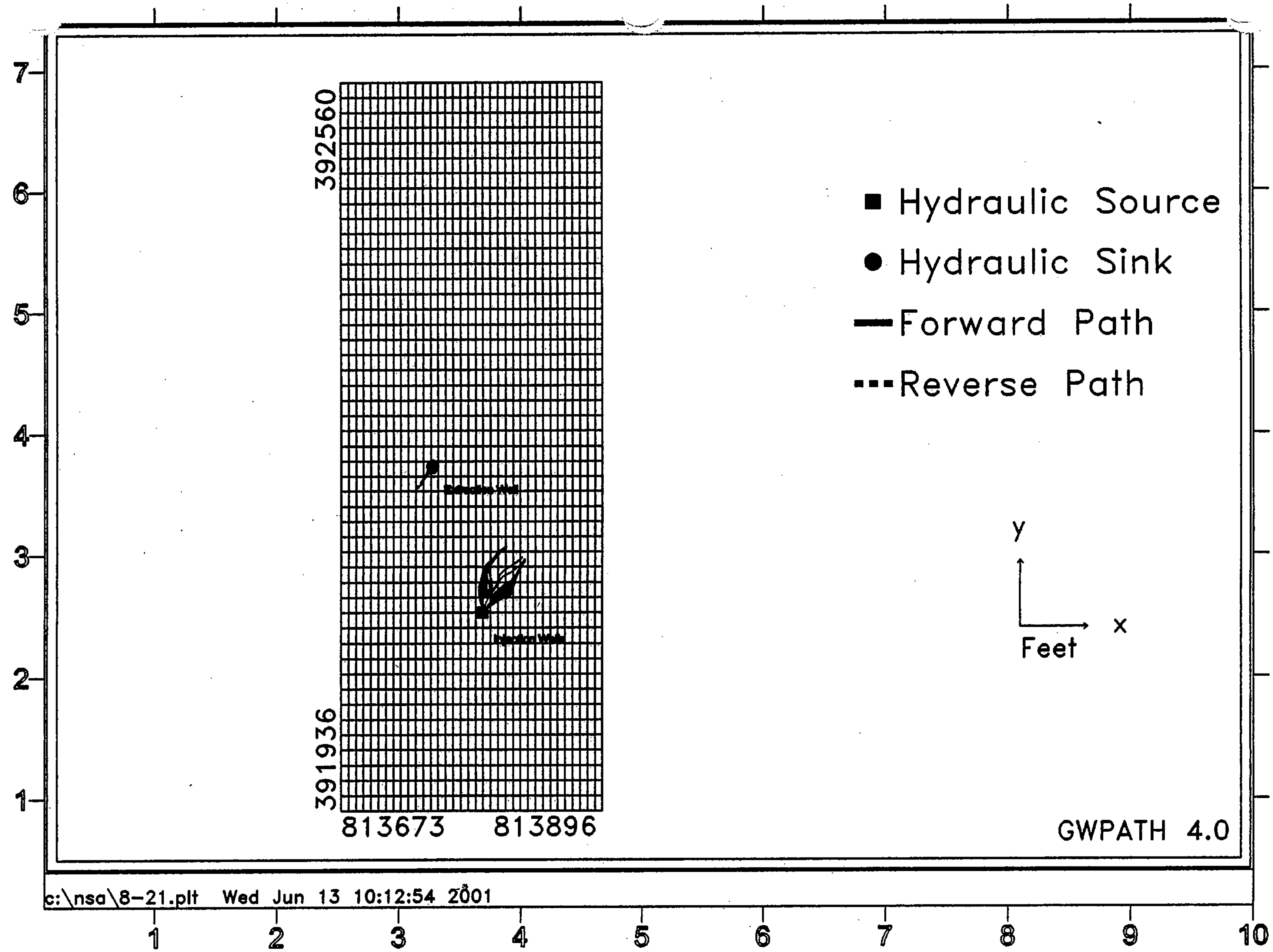



FIGURE 13
8-21-00 (~160 DAYS TRAVEL TIME)

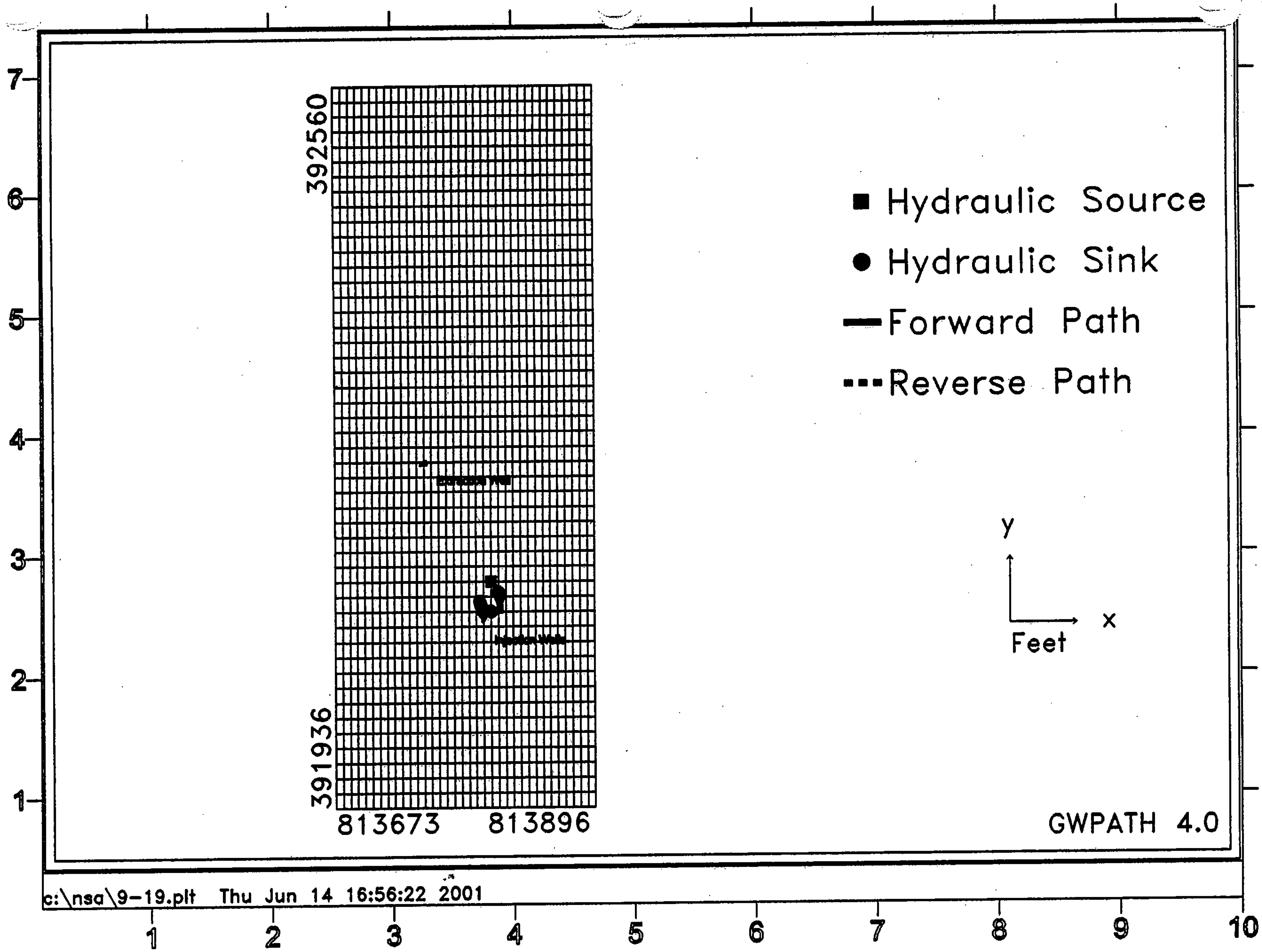



FIGURE 14
9-19-00 (~180 DAYS TRAVEL TIME)

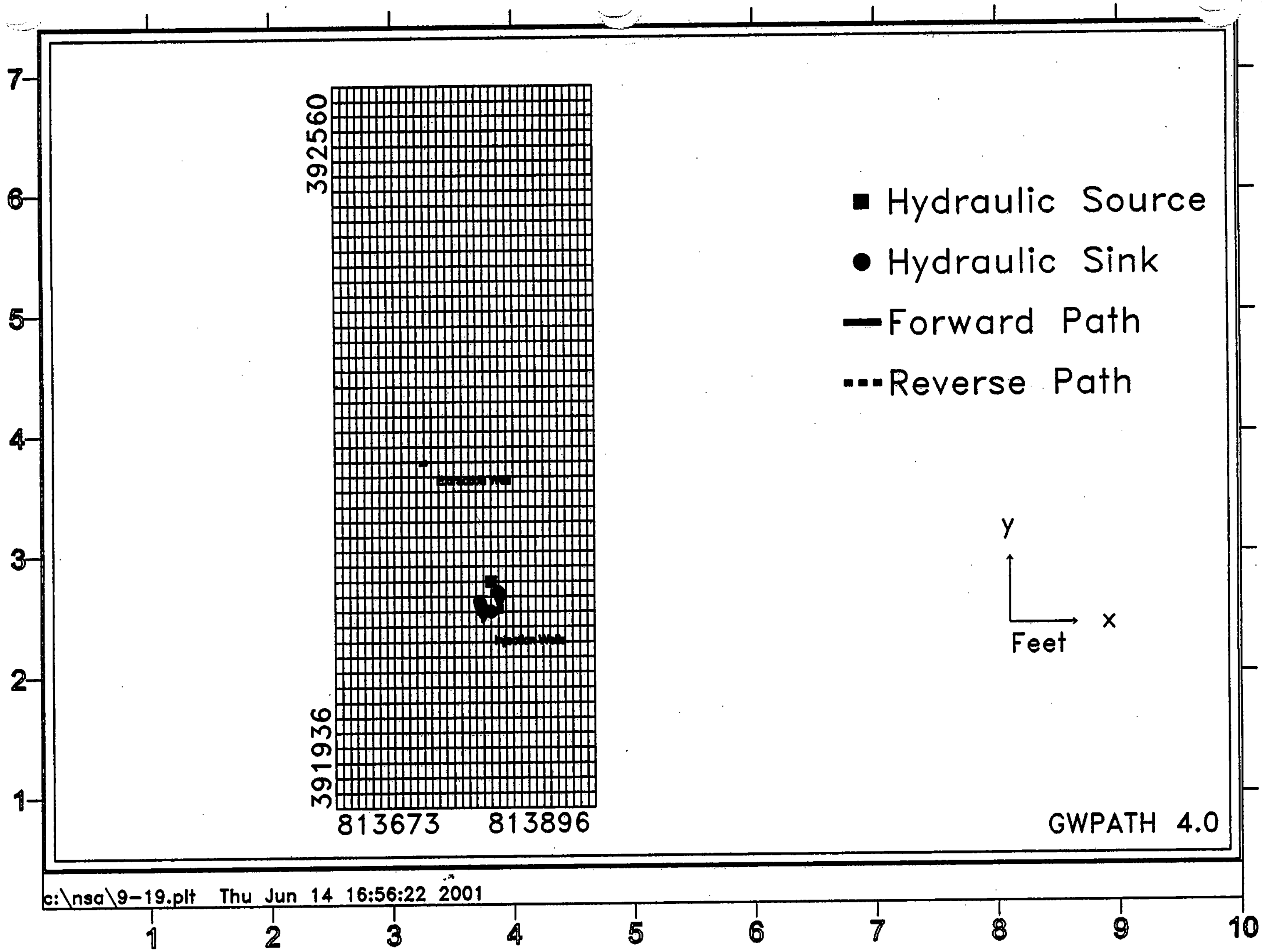



FIGURE 14
9-19-00 (~180 DAYS TRAVEL TIME)